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OF THE [redacted]
EXPLOSIVES SAFETY SEMINAR
ON
HIGH-ENERGY PROPELLANTS (7TH)

HELD AT

Carriage House Motor Lodge
Cocoa Beach, Florida,

24-26 August 1965 (U)

(11) Oct 65, (12) 40p.

Sponsor

ARMED SERVICES EXPLOSIVES SAFETY BOARD
Washington, D. C. 20315

Host

UNITED STATES AIR FORCE

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PREFACE

This is a record of the proceedings of the Seventh Annual Explosives Safety Seminar on High Energy Propellants held at the Carriage House Motor Lodge, Cocoa Beach, Florida, 24 thru 26 August 1965.

The Armed Services Explosives Safety Board (ASESB) sponsors the annual Seminar as a means of providing an exchange of current information on explosives safety between those segments of Government and industry concerned with high energy propellants. Selected papers are presented by the participants during the course of the Seminar, and a free discussion of the subject matter is encouraged.

The material contained herein represents reports and opinions of the participants, and is a product of the individual or organization which he represents. The ASESB does not vouch for the accuracy of the facts presented, and does not necessarily endorse the opinions expressed.

Rapid and widespread exchange of information concerning explosives incidents and accidents is a vital component of a cooperative effort on the part of Government and industry to develop effective means of prevention in their safety programs. Questions and comments concerning the material herein should be directed to the individual speakers or their organization.

The Armed Services Explosives Safety Board, Nassif Building, Washington, D. C., 20315, should be advised of errors or other corrections that may be required in the text.

Appreciation is expressed to all participants for their interest, and their active role in promoting the cause of explosives safety within the Department of Defense and in the industries represented at the Seminar.

R.E. Johnson
RICHARD E. JOHNSON
Captain, USN
Chairman, ASESB
October 1965

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EXPLOSIVES SAFETY SEMINAR ON HIGH ENERGY PROPELLANTS

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COL. LELAND S. McCANTS, USAF
CHAIRMAN, ARMED SERVICES EXPLOSIVES SAFETY BOARD
WASHINGTON, D. C.

This is our Seventh Seminar together ladies and gentlemen; many of you have participated in all of them and others are relatively new to the group. But whether you be old or new, we'd like to extend our warmest greetings to you and express our appreciation for your presence with us. It is our sincere hope that each of you will glean something profitable and of value from the papers that are going to be presented for certainly this is the purpose of this gathering each year. We would ask your indulgence in some of the equipment in the rear room. This was the nerve center of the Gemini 5 news media and we had quite a time getting them pushed back as far as we did. They had their problems and of course we had ours; therefore, we ask you to bear with us.

This year our host is the United States Air Force and they have, against quite formidable odds, performed very splendidly in our behalf. As you are no doubt well aware many tedious hours go into making the arrangements for a gathering such as this. A lot of people devoted both their time and energy in the form of countless hours. We are most grateful to all of these nice people and would like to express our sincere thanks to them.

It is with regret that I advise you this morning that General Huston will be unable to be with us and welcome you gentlemen. In addition to his duties as Commander, Air Force Eastern Test Range, General Huston serves as Deputy to the Department of Defense Manager for Manned Space Flight Operations. It is in this capacity that he was suddenly called away yesterday to Houston, Texas. Knowing General Huston, I assure you he sincerely regrets his inability to be with us this morning.

Representing General Huston we are privileged to have Col. E. W. Richardson, Vice Commander, Air Force Eastern Test Range, a position he has held since January 1964. Col. Richardson, prior to becoming Vice Commander, was Deputy for Range Operations at Patrick from May 1960 until January 1964. He is a Command Pilot having been commissioned a fighter pilot in October 1940. He is a Mechanical Engineer graduate from Rice University, Houston, Texas. Ladies and gentlemen, it gives me great pleasure to introduce to you at this time, Col. Richardson.

COL. E. W. RICHARDSON, USAF
VICE COMMANDER, AIR FORCE EASTERN TEST RANGE

Thank you Col. McCants. Ladies and gentlemen, its a pleasure to be with you this morning. I appreciate the opportunity to welcome you on behalf of the Air Force. As Col. McCants said, there are a lot of new ones and a lot of old ones around here. I can see several faces that I've seen around for some time. I think its one of the things that's good about the Service and Service associated industry - regardless of where you go, you'll find someone you've seen before. Col. McCants has picked out part of my speech. I was going to express General Huston's regrets that he couldn't be here, but he has done that most appropriately.

While we're talking Gemini, I guess you've all been listening to the radio and TV. It seems we've got the boys back on schedule so that they're eating and sleeping like they're supposed to and we have the power supply so that it would appear they can stay up there for the full eight days.

While talking shop just a little, I don't know whether you were here in time yesterday to see the Minuteman shot, it looked good. The people in charge of the program tell me that the data was collected and all we have to do now is play it back on the tape on the Twin Falls victory and go out with a couple of 130s and snatch it off and bring it back. This doesn't seem to be much of a problem but its a pretty exacting exercise. While you are here we will have another shot tomorrow. In looking at your schedule I see this is about coffee-break time. The Delta shot will go about 1000 hours. I think it might be appropriate if the managers of the program might slide things around a little and make this time available for you.

To go on with a few of the remarks that I have prepared, it seems to me that you've picked a very appropriate time for your get-together not only as it is summertime in Florida and I don't refer to the Gemini shot which has attracted a lot of attention to this area in the last few days, but I'm talking about other programs that are directly related to the activities in which you men are involved. Primarily the continued expansion of the use of solid propellants and particularly very large boosters. We have recently started and almost now completed the early development of an improved Minuteman solid boosted missile. The first shot in this particular series, Minuteman II, was fired only last September. As you probably know the Polaris program continues here and particularly on 18 June 1965 we had sort of a first and we fired a Titan III-C. The first in the sense it was a combination of solids and liquids although we have done this before as you know with a boosted Delta. The thrust of this particular booster was the most impressive part. The other part was that we counted down and fired

two solids of that size at almost the same instant, very close at least. We also fired the whole business rather than testing bits and pieces, we fired it all in one shot and it came out an unqualified success.

In addition to what's going on here, there is an awful lot of R&D going on in various parts of the country to make the maximum use of combinations of solids and liquids and to continue to improve on the motors themselves and the ingredients used to develop this high thrust. But where are we going, what's the future? It would seem that the combination of solids and liquids is a pretty good way to do a lot of things. The Air Force particularly is looking forward to the time when we can launch the MOL system with the Titan III-C. Additionally in the program there is a plan to put in orbit a couple of dozen communication satellites by firing on each one of the Titan III combinations, eight satellites that will be dropped off as they are gradually orbited around the world making the maximum use of the payload. And trying to get the most out of the solids, the booster itself, as we continue its development.

With the increasing use of solid propellants and certainly no great diminishing use of liquids, it is obvious that there is a proportionately growing need for safety measures to keep human and property risks at an absolute minimum. The Eastern Test Range has maintained a very good safety record during the decade and a half that we've been here since in that time we've had only four fatalities directly related to booster accidents. And no property damage except the palmettos around the area that we control. We've had a few missiles try to go back to the other side of the river in the early days and we've had a few of them slide off the pad and come down outside the confines of the particular compound. But we've been extremely fortunate, we're proud of this record and we'd like to continue. This certainly is where you people, your seminar and the ASESB come in.

The exchange of safety information by organizations associated with the propellant industry is one of the surest ways of meeting the ever-increasing requirements demanded in the development, manufacturing, transporting, storing and overall use of explosive materials. I've looked at your program and certainly there is an impressive list of subjects to be discussed and very qualified people to do this. I know that you will produce some very valuable results which will be fed back into the system and we here at the Range as we finally get around to using these boosters will be the one that profits.

I would like to say again we certainly appreciate the opportunity to have you with us this year, I hope you will have a very productive meeting and although the schedule is tight, it would seem to me that the planners since they arranged to be down here by some device will have planned some time for you to enjoy the Florida sunshine and come back and see us again. Thank you very much.

<u>Col. McCants</u>: You've just seen a busy man in action, Col. Richardson must be on his way. We appreciate his taking the time to come down and be with us this morning and I'm sure you join with me in this expression of thanks.

Each year Mr. Bruce M. Docherty, Assistant General Counsel, Office, Secretary of the Army is required to announce the rules of the game as they pertain to the conduct of the Seminar. Let me assure you his presence should in no way disturb you for he will act just as quickly in your behalf as he will in ours. We, I'm sure, will hear from him only, if and when, either of us get off the track; in such event he would nudge us gently back on course. Ladies and gentlemen, Mr. Docherty.

Bruce M. Docherty

Assistant General Counsel, OSA

Each year the Armed Services Explosives Safety Board has asked the General Counsel of the Army to make an attorney available for attendance at its Safety Seminar on High Energy Solid Propellants. Those who have attended prior Seminars are probably aware of the reasons for attendance of counsel. I will restate those reasons briefly.

The President has recognized that information and advice obtained through activities such as this Seminar are beneficial to the operations of the Government. He has prescribed certain standards for the departments and agencies of the Government to follow in order that committees and similar groups sponsored by the Government shall function at all times in consonance with the antitrust and conflict of interest laws.

This Seminar is being conducted in accordance with the standards applicable to this type of meeting. It is felt, however, that since any such meeting as this is subject to the provisions of the antitrust laws, a Government attorney should be present as an added protection to the Government and to all participants.

I am not here to present the full and free exchange of information. That would defeat the purpose of the Seminar. The primary reason for my presence is to guard against the inadvertent consideration of any subject which might bring the Seminar within some aspect of the antitrust laws. This is not likely in view of the excellent manner in which these Seminars are always conducted.

The agenda has been prepared with a view to permitting free discussion of the topics to be considered. I will be present throughout

all the sessions. If at any time I think we are getting into an area which might raise antitrust implications, I will call this to the Chairman's attention so that any such discussion may be avoided.

I will also be available during and outside meetings for the consideration of antitrust, conflict of interest or other legal problems which may arise. I should add that I have always greatly enjoyed these Seminars and that I am very happy to be back again today.

(Colonel McCants then introduced the Members of the Board and their Alternates who were present, as well as members of the Secretariat.)

Col. McCants: In accordance with the Charter of the Armed Services Explosives Safety Board, Chairmanship of the Board is rotated at three-year intervals between officers of the Military Departments. Many of you will recall that the Army occupied the Chair in the person of Col. Andy Hamilton prior to my Chairmanship which became effective 1 September 1962. Now, effective 1 September 1965, in accordance with current rotational policies, the Navy assumes the Chairmanship of the ASESB. The new Chairman, in the person of Capt. Richard E. Johnson, USN, a native of South Dakota, is with us today. Capt. Johnson graduated from the U. S. Naval Academy in 1938 and from the U. S. Naval Postgraduate School in 1946 with a specialty in Ordnance Engineering. His duties at sea have been predominantly in destroyers. Ashore he has had tours at the Naval Mine Depot, Yorktown, Va.; with the Naval Advisory Group in Korea; as Commanding Officer, Naval Ammunition Depot, Shumaker, Arkansas and as Assistant Chief of the Bureau of Naval Weapons for Field Support. Ladies and gentlemen, I would like to have you meet Capt. Johnson.

Much of Capt. Johnson's success as Chairman of the ASESB will depend upon the readiness of many of you people to assist and support wherever possible. I'm sure you will give him your unswerving support and I'm equally sure it will be deeply appreciated.

I would certainly be most remiss if I failed to take a moment to recognize the dedicated efforts of so many who have made my Chairmanship the genuine pleasure it has been. I've appreciated your support very much and I thank you.

For your information I am advised by the Air Force that I am to remain with the Board as the Air Force Representative on the Secretariat thru June 1968. I assure you I am looking forward to our continued association.

Last year, many of you will recall, I announced that this year's Seminar would include, insofar as possible, those presentations which you as individuals considered most important to you. I indicated you would have ample opportunity to make your wishes known. I believe that we kept this promise and this year's agenda reflects this effort aimed at making your participation here as interesting and profitable as possible. In this connection I'm sure you'll find such presentations as "Legal Liabilities" and "Environmental Pollution Abatement," to mention but two, most informative.

L. M. JERCINOVIC
SANDIA CORPORATION
SANDIA BASE
ALBUQUERQUE, NEW MEXICO

I'd like to say a few words about Sandia Corp. - what we are doing and why we are here. Sandia is a wholly owned subsidiary of the Bell System. We're prime contractor to the Albuquerque Operations Office of the Atomic Energy Commission. Our main mission is nuclear weapons development, testing, manufacturing and certification. We have 8,000 employees generally located in our three laboratories, one in Albuquerque our headquarters, one in Livermore and the other at Tonopah, Nevada. We also have resident personnel pretty much scattered around Johnston Island, Hawaii, Point Mugu, Mercury, Kennedy, White Sands, and we even participated in recent operations at Raratonga and Fort Churchill, Canada.

In the execution of our operations, a very large part of our job is the certification and testing of all the components that go into nuclear weapons. We have at Albuquerque a very large environmental testing facility. In our testing of these various components we use a great many electro-explosive devices. Fortunately, we haven't had too many mishaps or accidents, we've had a couple. Some of them made the headlines. We haven't killed anyone, but we hurt some people once or twice. We have some fairly rigid safety requirements that pertain to all operations in the field using these electro-explosive devices.

Our present safety criteria call for the usual kind of visual observation, if you hear thunder or see lightning, you just suspend operations. We also have a static field gradient criterion which we have established rather arbitrarily at 1500 volts per meter. Albuquerque as you may know (certainly Col. McCants will remember since he was stationed at Sandia Base) has a very high and dry climate, lots of wind, lots of sand, quite a few thunderstorms during the summertime. Our static problems are quite pressing, we're quite concerned about them. Certainly we do not wish to induce any inadvertent ignition of our devices. We suspend operations during the conditions that I mentioned. If they are sensed, we knock off operations and go hide. We think this is a rather expensive process and our field test and environmental test people have raised a very serious question, prove your point to us. We have been trying to do that this summer.

The last couple of months we have been spending quite a bit of time doing a literature search primarily from all the available sources that we can to try to find some support and backing, additional information or something that would help us confirm our point of view on safe operations in the field. We've called many people, maybe some of you sitting in the audience. We've tried to run down some experts

in the field to try to get guidance and advice and leads to where we could go. Part of the plan of today is to give you some of the results of what we have found out and some of the things that we have done at Sandia.

We have this morning, one of the four scheduled talks that we have prepared. Bob Gentzler from our Field Testing organization is going to talk about an atmospheric static electric warning system that he has developed at Sandia and will give you some of the details of how it was set up, what makes it work and some of the results that we have obtained from it. I would like to request, and this was part of our request to the Armed Services Explosives Safety Board earlier in the summer, your help in helping us get the answers that we need. To this end we had requested to have some time this evening with those of you who could spare the time. We'd like to ask you to come back after dinner and sit with us and sort of listen to the rest of the talks that we have scheduled that are short, ten minutes or less each, and tell you some of the things that we're doing and we'd like to try to pick your brains if we can, for some leads and guidance into other areas which may impinge or relate directly to our problem.

Our problem specifically is, we would like to set a standard, a legitimate standard that we can prove, on what is a good safety criterion for use in the field. Many of the electro-explosive devices that we use are standard commercially available jobs. All of you I'm sure are familiar with them. Many of them we obtained directly from the military organizations. Many of them are quite sensitive, some of them are not sensitive. We at Sandia are trying to eliminate the very sensitive devices by embarking on a rather ambitious program of designing high energy igniting replacements for these things. But of course these things take time and money and it will be quite a while before we get th[illegible] all replaced. We do have a program along that line.

Tonight John Weber from our Explosive Device Development, Design [illegible] Testing Group would like to discuss some of the things that are [illegible]g on at Sandia towards this end of designing these less sensitive de[illegible]ces, and some of the characteristics that we have found in our de[illegible]lopment program. Also Phil Brooks of our Explosives Research Dept. will deliver a very short discourse on the results of our literature searc[illegible] so far. The last presentation this evening would be a discussion by Do[illegible] Rost who is the supervisor of our Safety Engineering Dept. on a fie[illegible] experiment we have fielded at the Langlier Atmospheric Rsearch Lab [illegible] the Magdalena Mountains in conjunction with the Bureau of Mines and the New Mexico School of Mines. They have that mountain tremendously instrumented to be able to tell just exactly what's going on as far as atmospheric static conditions are concerned and they invited us up to set out an array of electro-explosive devices with all the various leads and antenna that we could anticipate or think about. We have had that up for a short time and we have had some very startling and, I think

you'll find, some very interesting results. Tonight Don Rost will discuss that experiment and what we have found so far. I'd like now to solicit your attendance this evening, those of you who can come, at 8 pm to sit and talk with us for about an hour. That includes the presentations and the discussion, longer if you desire, but we certainly would like to beg your assistance in helping us establish a program.

We might even go so far as to suggest that this particular problem might even warrant subcommittee status on the ASESB. I haven't talked about this with Col. McCants or any of the other people - this is off the top of my head, so maybe this is presumptuous of me, but I would certainly think that this program, as far as we have been able to discover, is a serious and pressing problem, not only at Sandia, but everyplace that we have been where we've sought advice and guidance, we've found the same problem. Stick your head in the sand; most of the people listen for lightning and thunder and run. We think there is a line closer to the field that can be drawn. We would like to try to draw that line.

Without further ado, I'd like to present Bob Gentzler.

ATMOSPHERIC STATIC ELECTRICITY WARNING SYSTEM

Robert F. Gentzler
Sandia Corp.
Sandia Base, Albuquerque, N. M.

I would like to discuss with you today the Sandia Corp. Atmospheric Static Electricity Warning System and show how it provides information to test personnel handling devices sensitive to this natural phenomena. Before describing the system, I will present a brief background on the measurements.

Atmospheric electric measurements were first made by Lemonnier, who in 1752, detected an electric field during fair as well as foul weather, and later by Coulomb, who in 1795, found that the air was electrically conductive. In the first half of the 19th century, these revelations of electrification of the atmosphere stimulated efforts to measure and comprehend the elusive qualities of atmospheric static electricity.

The physical basis for the correlation between atmospheric electrical conductivity and the amount of airborne non-radioactive particulate matter is now well understood and verified. Dust particles are surfaces upon which conduction ions of the atmosphere diffuse to become immobilized, leading to a measurable loss in conductivity. If the dust content rises, the conductivity falls (potential gradient increases) and vice versa. The distribution of particulate matter then, in a very real sense, represents one of the dynamic factors in the changes in the potential gradient of the atmosphere. Local environmental conditions control the injection of particulate matter into the lower air strata, and continuing but irregular convective and diffusion processes cause large variability in readings of potential gradient in limited distances.

On a much larger scale, electric fields from other sources are superimposed on the variations of the fair weather field resulting in a complex potential gradient pattern. These sources include 1) air mass changes accompanying frontal activity, 2) migratory pressure systems & associated weather, and 3) thunderstorms with lightning discharges.

The purpose of the instrumentation system which I will describe is to measure, record, monitor, and warn users (within certain predetermined limitations) of the existing atmospheric static electricity levels as indicated by the earth's vertical potential gradient in an area encompassing Sandia Corporation's testing activities in Albuquerque. From the study of these measurements, an early warning service of

impending changes in potential gradient levels is provided to organizations conducting testing programs sensitive to these phenomena.

In an electric field, potential gradient is measured in voltage per unit length. These measurements of the potential of a point in the air have been made for many years using several different types of probes by which a conductor will assume the same potential as the air in its environs. Then, the potential difference between the conductor and the earth can be measured using some form of electrometer or electrostatic voltmeter. Among the instruments commonly used are the field mill, metal spheres and needles, and the radioactive probe. The field mill, an adaption of the Faraday cage, consists of a conductor which upon rotation is alternately exposed to the free air and a cage. The conductor assumes the charge of the free air, and upon rotation the cage assumes the opposite charge which is measured relative to ground. Metal spheres and needles, the second type instrumentation mentioned, when highly insulated from the earth will also assume the free air charge which can be measured relative to ground. Finally, the radioactive probe functions on the principle that the potential of the conductor is made equal to its surroundings by ionizing the air close to the conductor, so that ions carry the charges away from the conductor which makes it equal to its environment.

The radioactive probe was selected for our use because it offers the advantages of little or no maintenance over an extended period of time, a stable output, ability to better sense changes in gradient because of the coupling effect of the radioactive ionizer, and almost all-weather operation.

The devices which we are using at Sandia Corporation test areas for potential gradient measurements are commercially available components which have been utilized to build a warning system. (Slide 1) The basic components consist of the probe and associated power supply, indicating meter, and recorder. The probe is approximately two feet tall and has a small piece of tritiated foil mounted on the probe cap. In the barrel of the probe are the associated electronics which will allow the power supply to be remotely located from the probe. The power supply cabinet has an indicating meter with adjustable alarm limits which trigger a horn and light when the preset alarm measurement is exceeded. A small recorder with a 30-day chart roll of pressure sensitive paper provides a record for evaluation and study.

This basic unit has been used to build a six-station network with the units arranged either singly or in pairs. (Slide 2) The system consists of six probes located in an area of approximately 150 sq. miles. The readings are telemetered over telephone lines to a centrally located master control station. At the master station are located the power supplies, recorders, and indicating meters. The data are monitored at this location. In addition to the master control station, four

repeater stations are located in the test areas. These repeaters serially indicate the readings of the basic probes. (Slide 3) Here is a typical installation of the basic sensor in a test area. (Slide 4) Again, the basic sensor is mounted on top of a 20-ft. pole in an area remote from operations, but available to the public. Mounting on the pole has prevented vandalism. (Slide 5) Here is shown the master control station. These meters indicate the potential gradient in kilovolts per meter for all stations which in turn are recorded here. This meter indicates the station number being serially sampled for the repeater system, and this meter indicates the reading of the particular station. These meters show the power supply for each sensor. (Slide 6) This is the remote repeater station with the potential gradient in kilovolts per meter and the station identification indicator.

In addition to the basic six-sensor system, we have in use several single probe systems and a system consisting of two probes.

The equipment is capable of monitoring on two ranges: plus or minus 1 kilovolt per meter; and plus or minus 5 kilovolts per meter. Monitoring on the six-station network is normally on the 5 kilovolt range. Background or fair weather data are usually studied on the 1 kilovolt range. An alarm feature operates a flashing red light and a buzzer when preset limits are exceeded. A reset circuit cuts off the alarm every 20 seconds so that changes in gradient will be indicated properly. A fail safe design causes the alarm to operate in the event of circuit failure. Continuous unattended operation of the system is possible for gathering of data for study purposes. The recorders turn at one inch per hour, and chart life is 30 days per roll.

For test areas where fixed installations are not feasible, a hand-held portable instrument utilizing the same sensor and powered by batteries is being used. (Slide 7) This instrument is held pointing toward the area of interest and at about waist height. It is available in either a 0-1 or 0-5 kilovolt range.

Next, I would like to describe the geographical layout of our system in the Albuquerque area and show you some examples of the data we have taken, comment on the associated natural phenomena, and discuss the uses of these data. (Slide 8) This map, made by the U. S. Coast and Geodetic Survey, is oriented with north at the top. The Rio Grande Valley and River lie north-south. The Sandia Mountains, also running north-south, lie on the east side. The black square represents an area of one square mile. The elevation of the river is about 5,000 feet and the mountains to the east rise to almost 11,000 feet. This elevation difference is a major factor in the development of cloud activity. Our primary testing area is located in the region outlined by the circle. The six potential gradient probe sites surround the test area and include known areas of storm activity. Station A is located to detect storms from the southwest, Station B to detect storms from the northwest, Station C for clouds over

the mountains. The three other stations, D, E and F, are located in the test areas proper at the sites indicated. Station F also serves as a detector for storms moving in from over the mountains to the southeast. Our general area of concern encompasses about 150 square miles. Telephone lines are used to transmit the signal to the master control station, near Station D. The longest phone lines correspond to the distance of the farthest site - about 18 miles.

These recordings of potential gradient are typical of fair weather with few clouds and light winds. This is the most frequently observed trace of background and usually runs 150 to 250 volts per meter. (Slide 9)

The next example shows the gradient trace when a single isolated cloud cell drifts by in an otherwise fair weather condition. The time scale on these records is one inch per hour. The next example shows a series of cells as they drift with changes in polarity. The spikes are lightning discharges. This record is very typical of potential gradient during thundershowers. (Slide 10) The first example is another case of thunderstorm clouds with lightning discharges. Notice the short period of time between fair weather gradient and high potentials. The next example shows the potential gradient during the wintertime when snow showers are present. A snow shower, in terms of its effect on potential gradient, is much the same as a thundershower, even though the moisture is in the form of snow rather than rain. The wintertime precipitation in New Mexico is frequently of this type so we have the associated gradient problem. The next example shows the gradient when wind picks up dust particles in the lower layers of the atmosphere. During the spring months, this phenomenon is frequently observed.

(Slide 11) Now I will show recordings from different stations on the same time scale. The horizontal line is identical time at all stations. This station shows the existence of a gradient field and about 10 minutes later the cell has moved sufficiently so that the next station is affected. The check marks on these examples indicate the arrival of the electric field at later times. The fifth trace is from a station not affected by this family of cells. From these data and knowledge of winds, early warning notices are issued to testing groups. (Slide 12) This slide shows another case of five different stations with a time lag indicated by check marks. Notice that all the stations do not indicate the same level of potential as the cells pass by because the stations are at different distances from the moving cells.

Now to discuss the data and its use: First, we have found that a skilled observer is needed to interpret the data, particularly when prognostications are to be made; the instrumentation is an aid, but it is most difficult to eliminate the human element. Second, the readings from the instrumentation should be believed until it can definitely be determined that equipment failure has occurred. Third, natural phenomena that cause electric fields are extremely complex and

change rapidly. This rapid change results in short time periods between first indication of a rising field and high readings. As a consequence, not all cases can be predicted in sufficient time for warnings to be issued. Therefore, personnel handling sensitive devices should be indoctrinated regarding these phenomena.

In conclusion, the static electricity measuring equipment at Sandia has been helpful in this problem by providing a warning service and as an aid to personnel who use the "look out the window" technique. However, the instrumentation has not completely eliminated the problem or replaced human judgment. If there are questions, I will attempt to answer them.

King, NASA: You've touched on a subject that's pretty near and dear to our hearts and I came in a little late, I'd like to ask several questions. Do you use Spherex Meters in addition to the potential gradient meters that you've described here?

Gentzler: Not at the present time.

King: What is your arbitrary danger level in KV per meter?

Gentzler: We essentially have said 1500 kilovolts per meter. I would like to qualify that.

King: You mean $1\frac{1}{2}$ KV?

Gentzler: Yes, 1500 volts per meter. I would like to qualify that a little bit in saying that there are other factors involved in setting the limitation than just a cut-off line, and this of course depends upon the devices being tested. There are some people who are handling particularly low threshold devices that prefer to quit testing at a lower level or test at a different time. Others feel that there is a higher level that could be set. This evening one of the gentlemen of our group will discuss these type devices and some of the efforts that we are presently making to give a more definitive answer to this particular question.

King: Do you use a rate-of-rise meter in connection with this and what time intervals do you have between first detection and to the point where it gets to cut-off?

Gentzler: We do not use a rate-of-rise meter. Such equipment is available. It has some merits - its a subject open to discussion. From the other phase of your question as to what is the time involved here - after observing these records for several years now, I would say that the time interval is from the order of seconds upwards to the order of an hour.

Several slides I've just shown here indicated that in the order of minutes we went from zero or near zero to over 5 KV per meter. I've seen this many times. Consequently, if you want to take the time rate of change involved in one of these very fast build-ups, you again have the problem that you're not going to be able to poke the button and eliminate human error quickly enough to take care of how fast the phenomena changes.

Filler, NOL: You make your gradient reading at one point aboveground, what possible role does it play, the variation of that?

Gentzler: On the equipment that we have there is an adjustment to take care of location of the probe at a level higher than one meter. While we measure in kilovolts per meter and actually you can say the probe should be one meter if we put it up 20 ft. in the air, then we have an adjustment within the calibration parts of the equipment that takes care of that.

Mondano, Custom Materials: Have any attempts been made to reference these voltages in some way to available energy in the area that you're scanning in terms of joules of energy? You mentioned voltage measurements with respect to energy? Any comments on that?

Gentzler: We do not make any measurements of this kind at the present time. Perhaps I've got a little comment here that would answer your question. The electric current carried in some return streamers of lightning flashes has been found as large as 200,000 amperes. If you take 200,000 amperes at some voltage, pick any voltage, this is going to be quite a lot of energy involved. Of course, the other side of the question there is what is the distance factor, how close are you to this form of energy. We can take this instrumentation that we have here and we can go out 30 miles from a thunderstorm and we can get an indication on the meter. We can also go within a half of a mile of a thunderstorm and we get quite a lot of different indication on the meter. So you've got to solve the distance problem in relation to the phenomena prior to the time that you can make an energy calculation using this equipment. I know of no equipment which measures energy directly at the present time.

Jercinovic: Tonight we hope to get some of you back to help us talk about some of these questions like Mr. Mondano had. We are really fighting this instrumentation problem. We would like to get some help. If any of you know any instruments that are available that would be applicable to our problem, we'd love to hear of them. They had a beautiful electrical storm last Sunday on Magdalena Mt. and some of our devices were ignited. The Laboratory is trying to now to give us the data that surrounded these particular events. We'd like to get as much guidance as we can from this group before we go home to try to plot our course for additional action that we've planned to do.

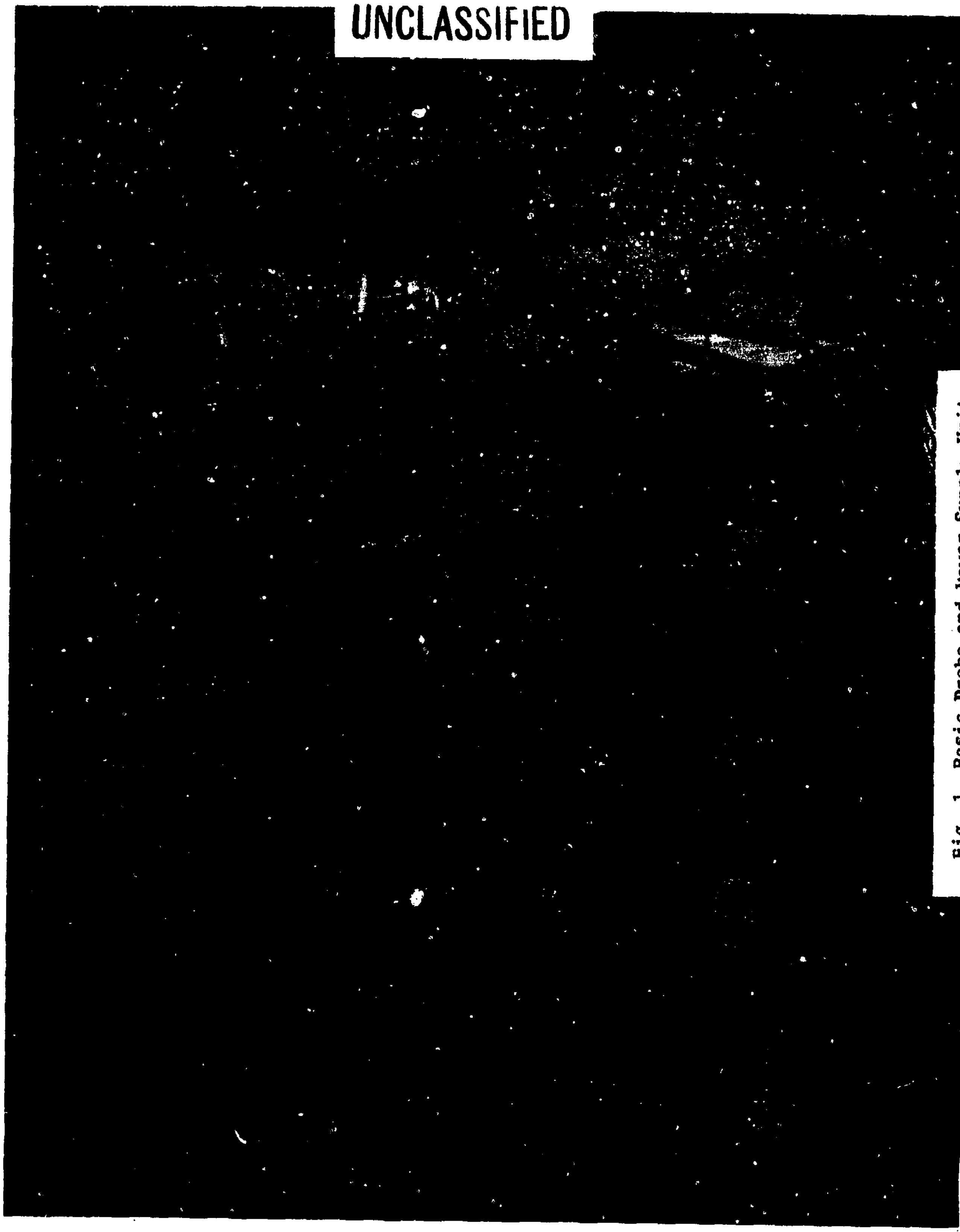
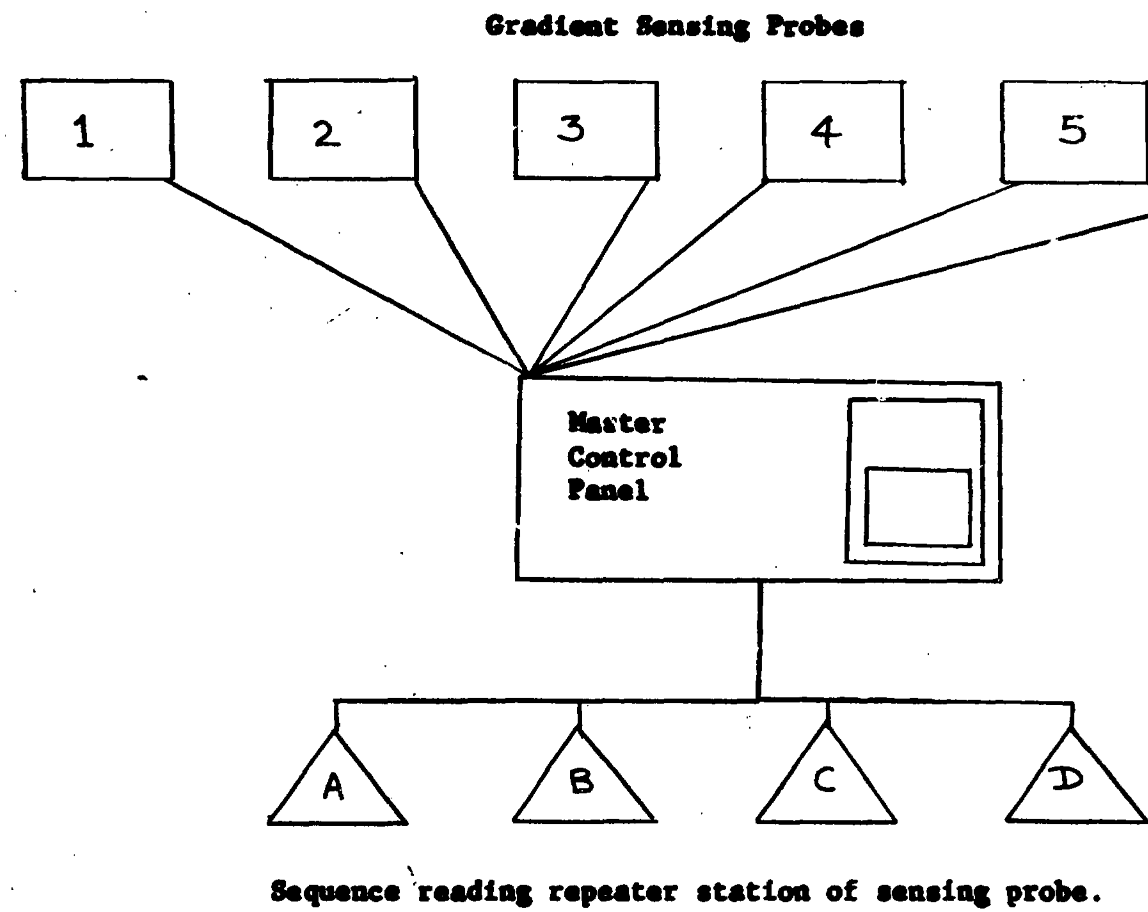


Fig. 1 Basic Probe and Power Supply Unit



BLOCK DIAGRAM ATMOSPHERIC STATIC ELECTRICITY WARNING SYSTEM. Fig. 2

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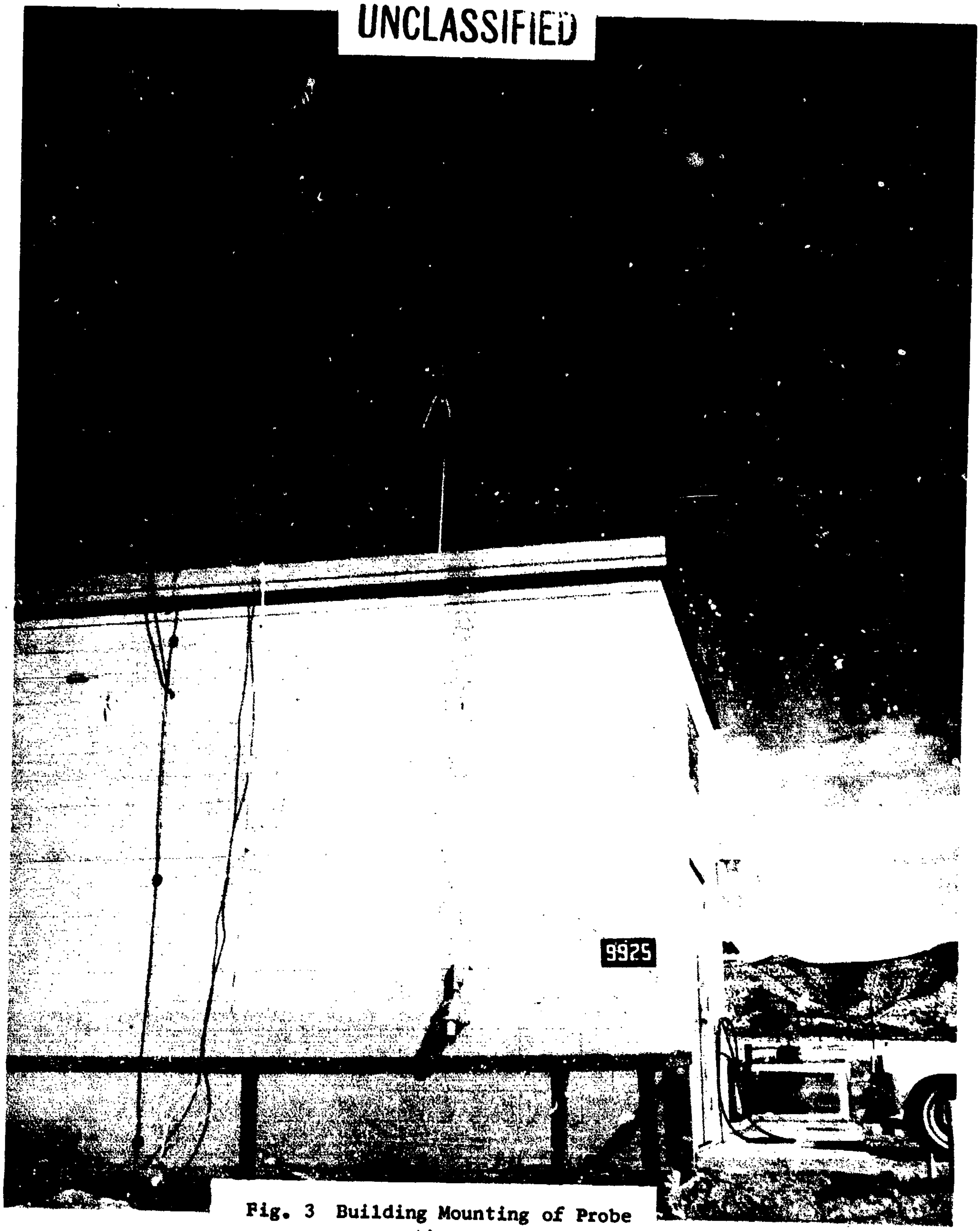

Fig. 3 Building Mounting of Probe

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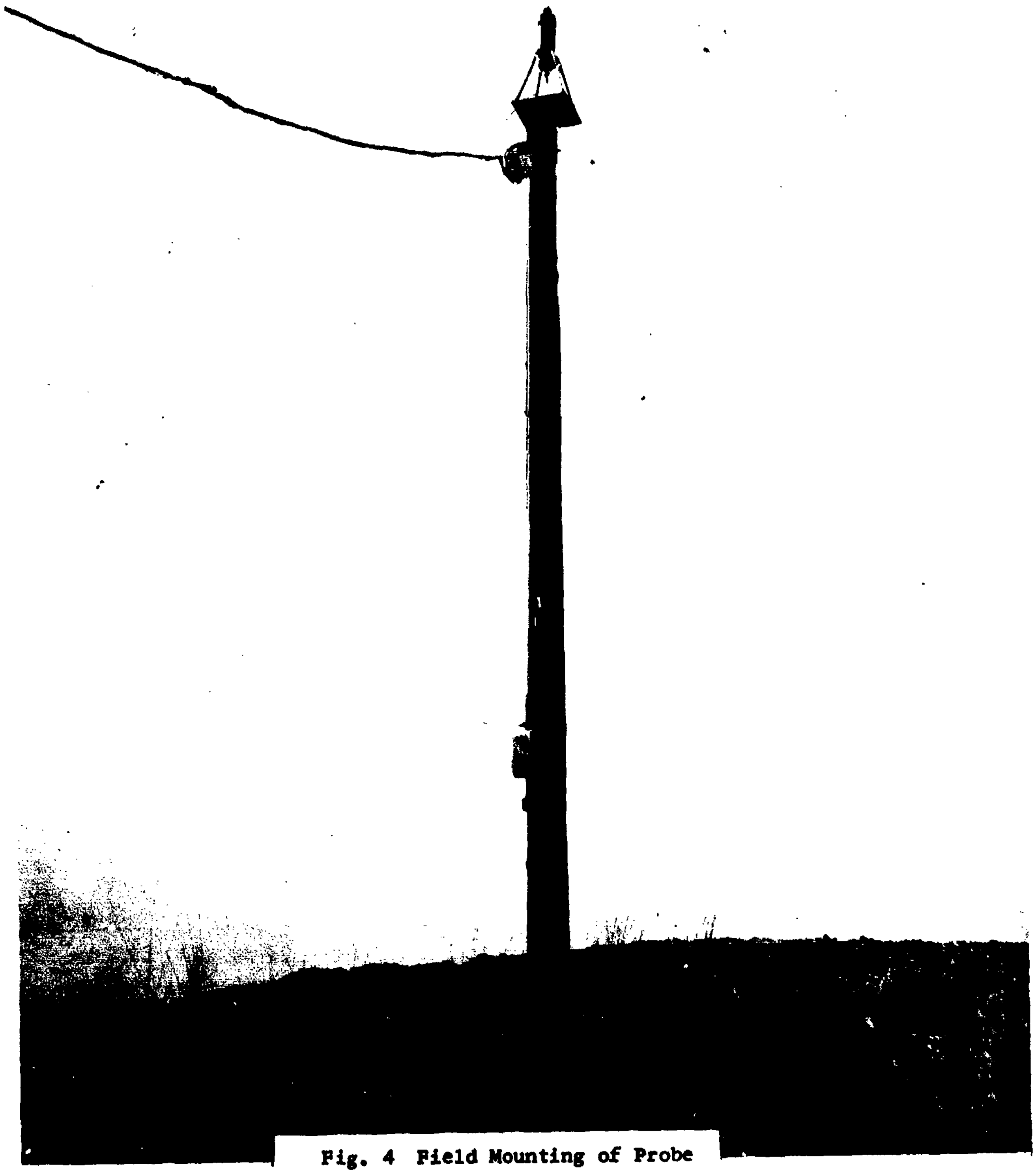


Fig. 4 Field Mounting of Probe

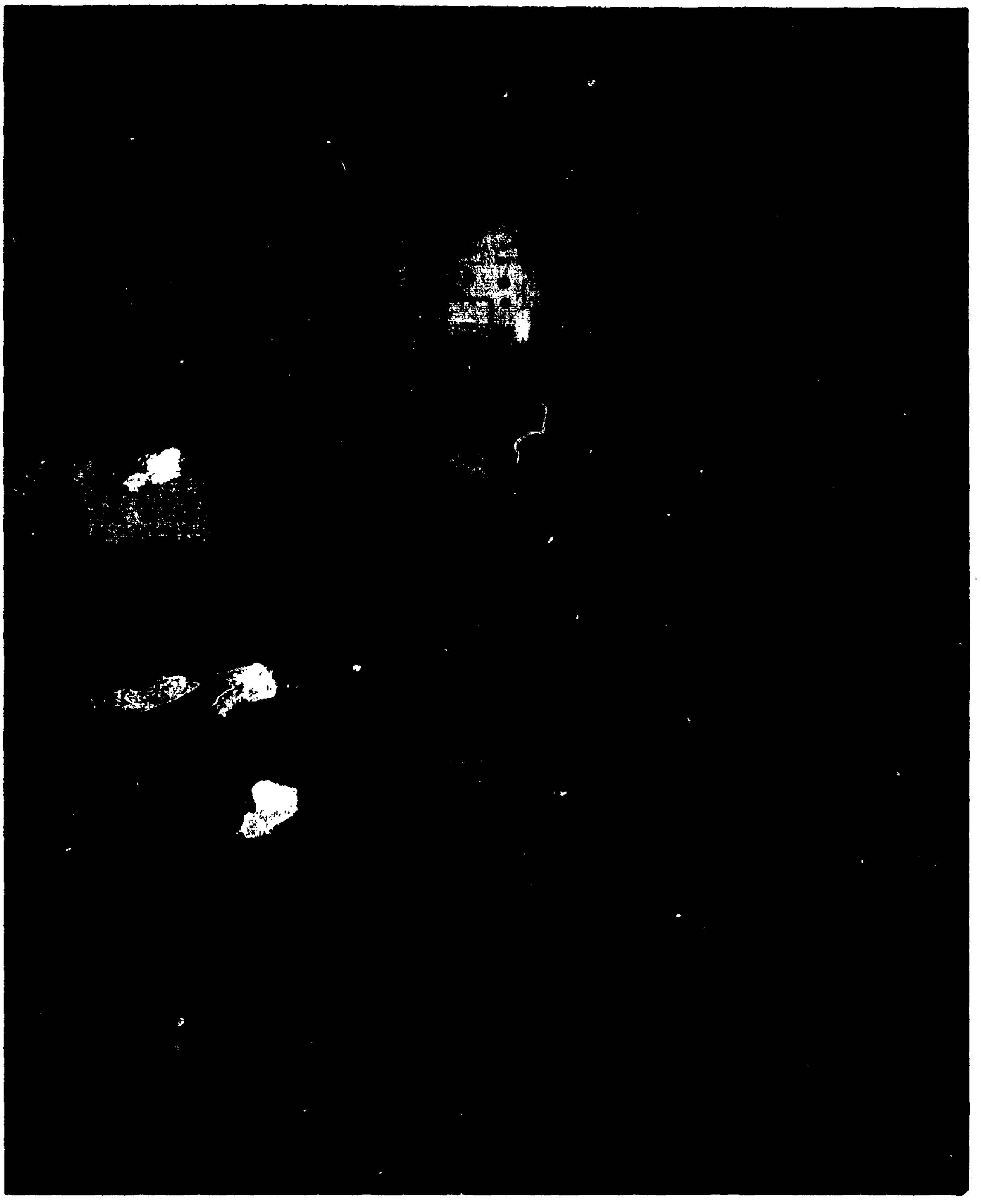


Fig. 5 Master Control Station

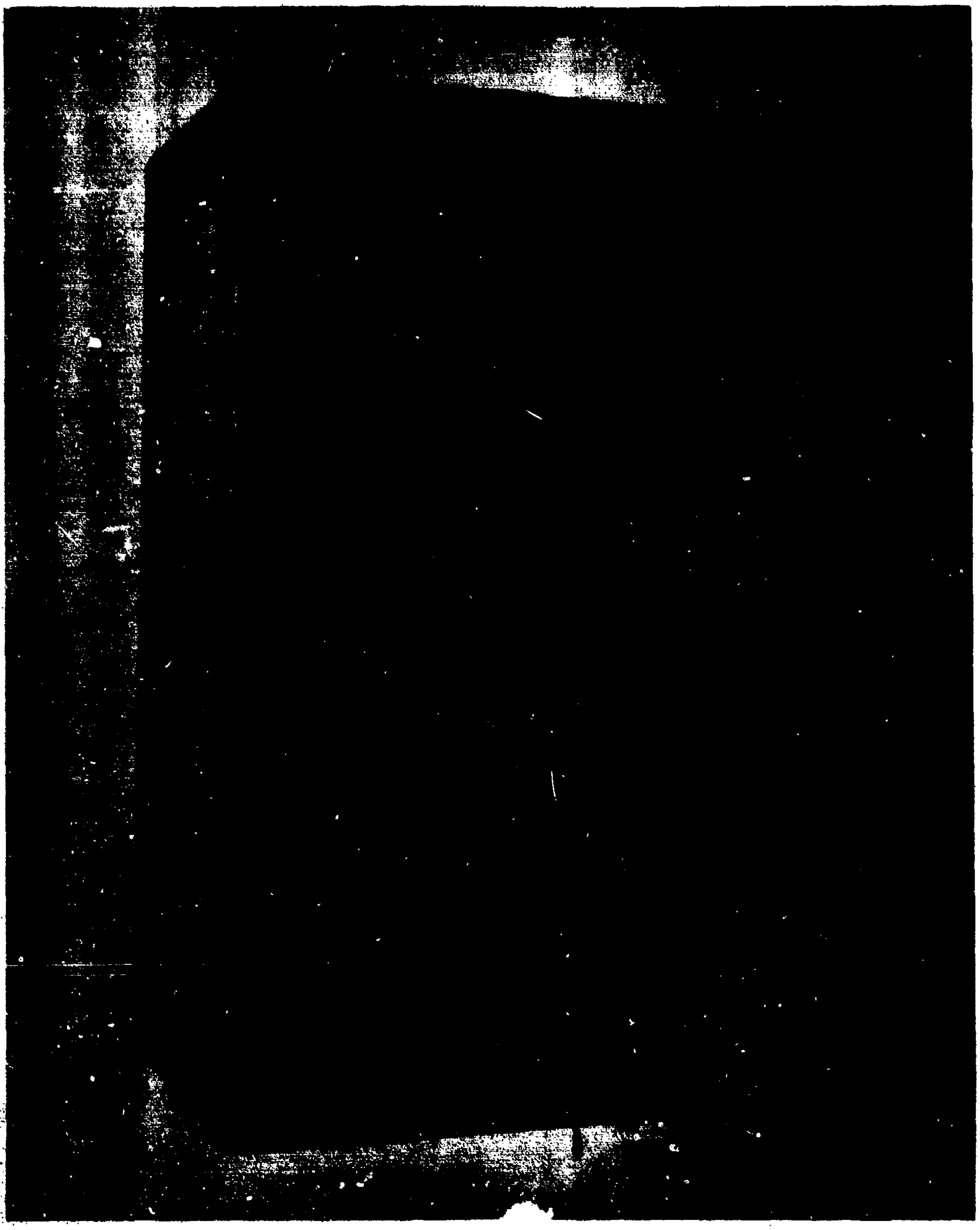


Fig. 6 Remote Repeater Unit

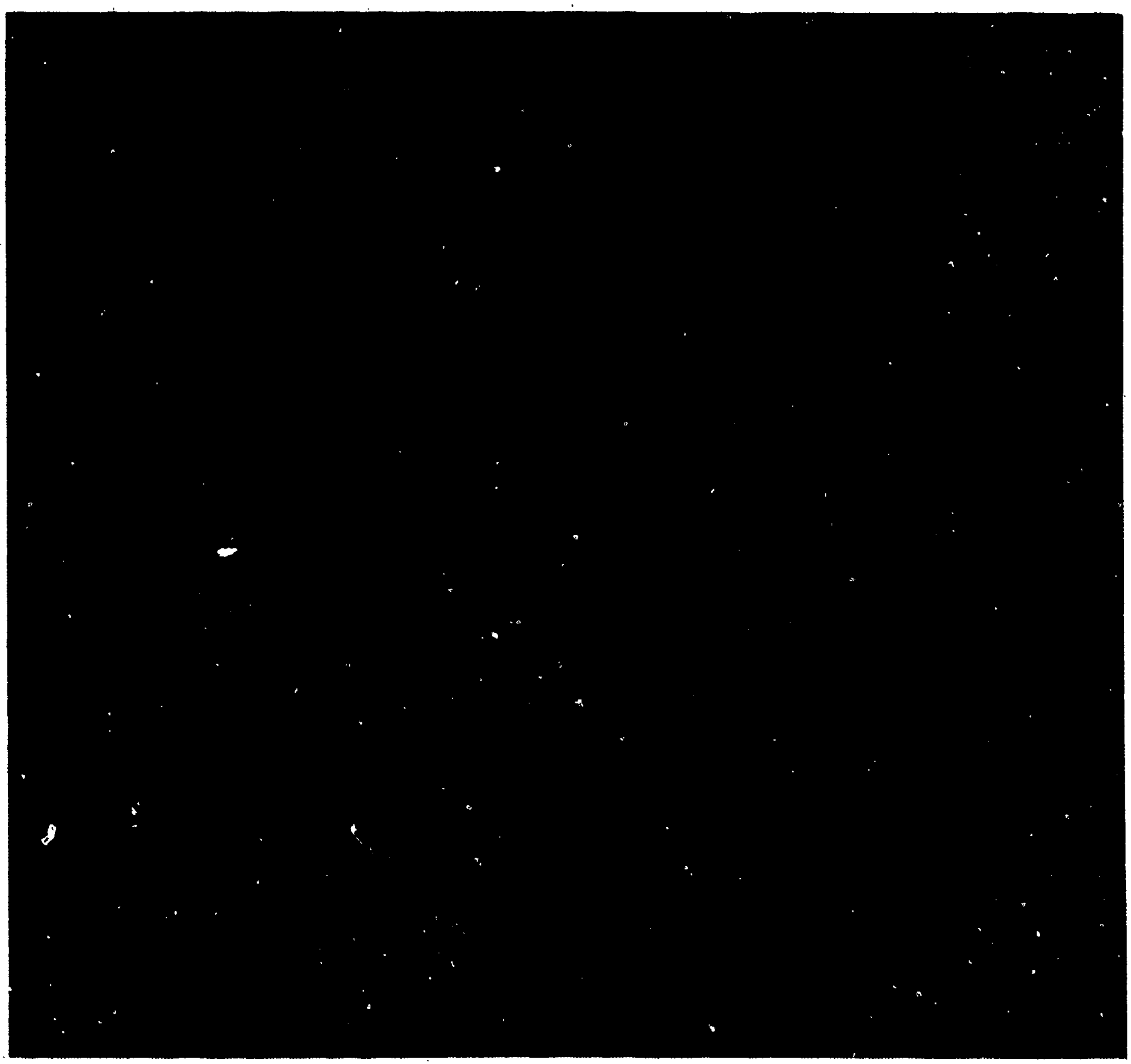
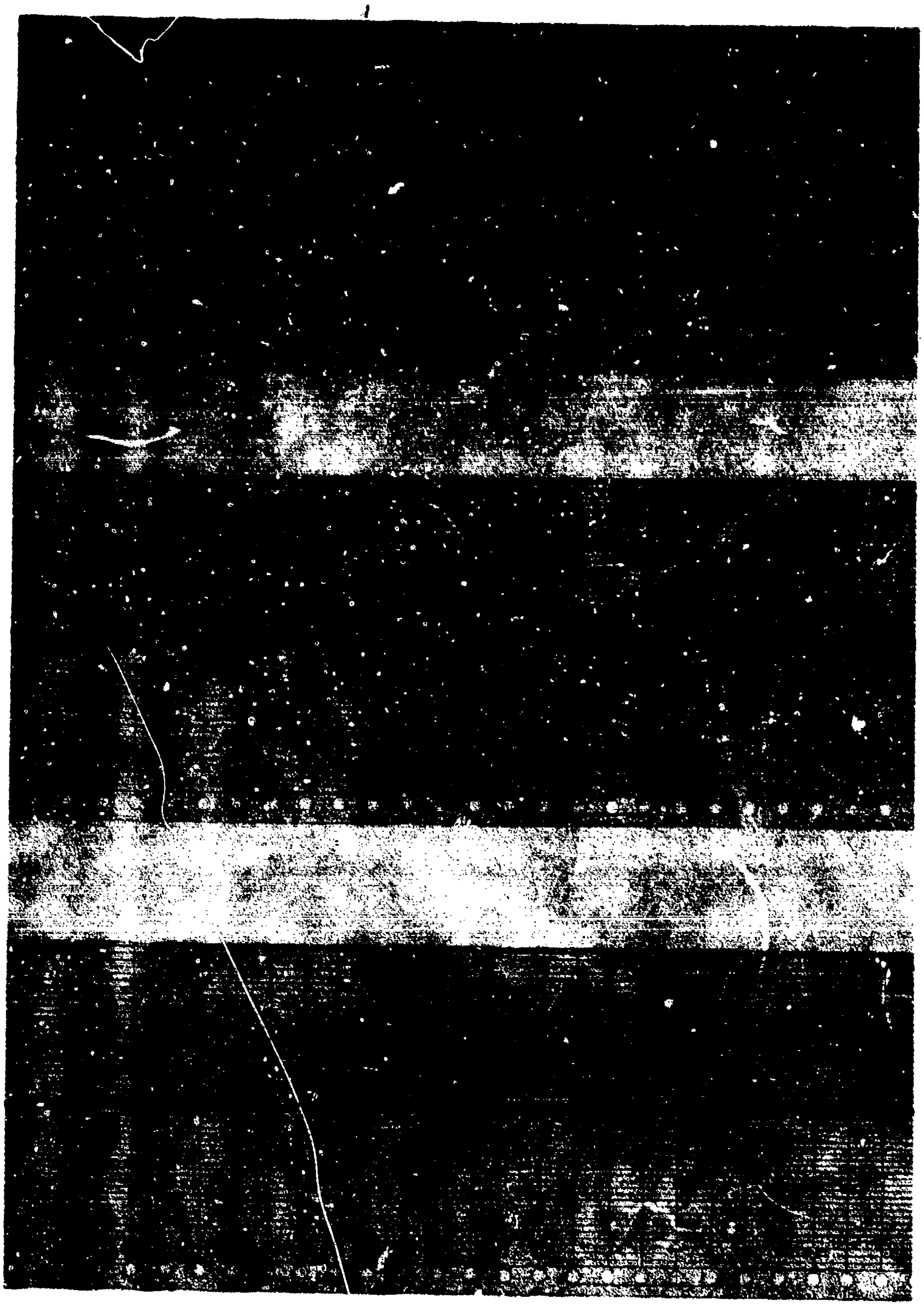


Fig. 7

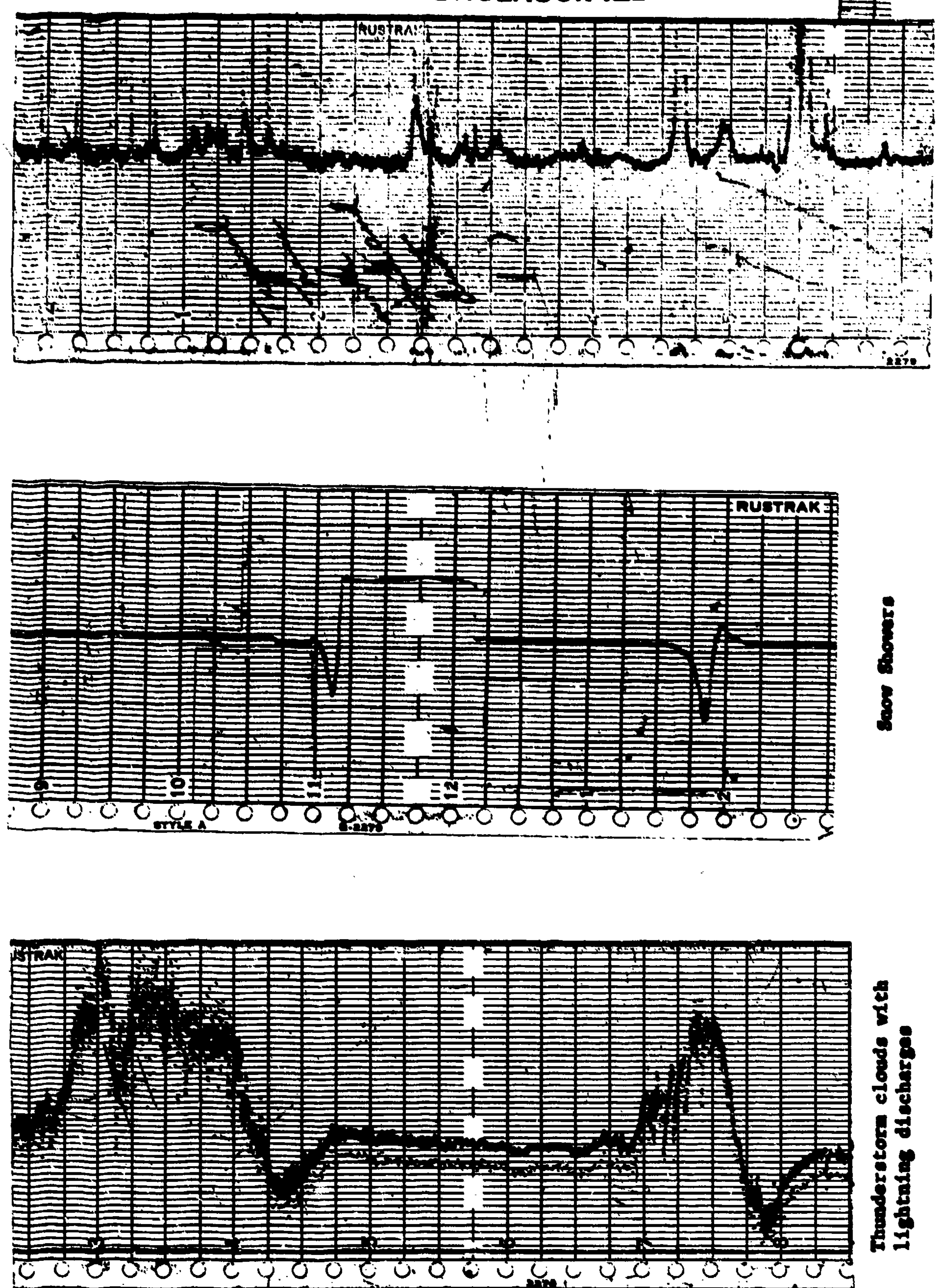


Normal Fair Weather Gradient

Single isolated cell in otherwise fair weather condition.

Changes in polarity as cells drift by. Spikes are lightning discharges.

Fig. 9

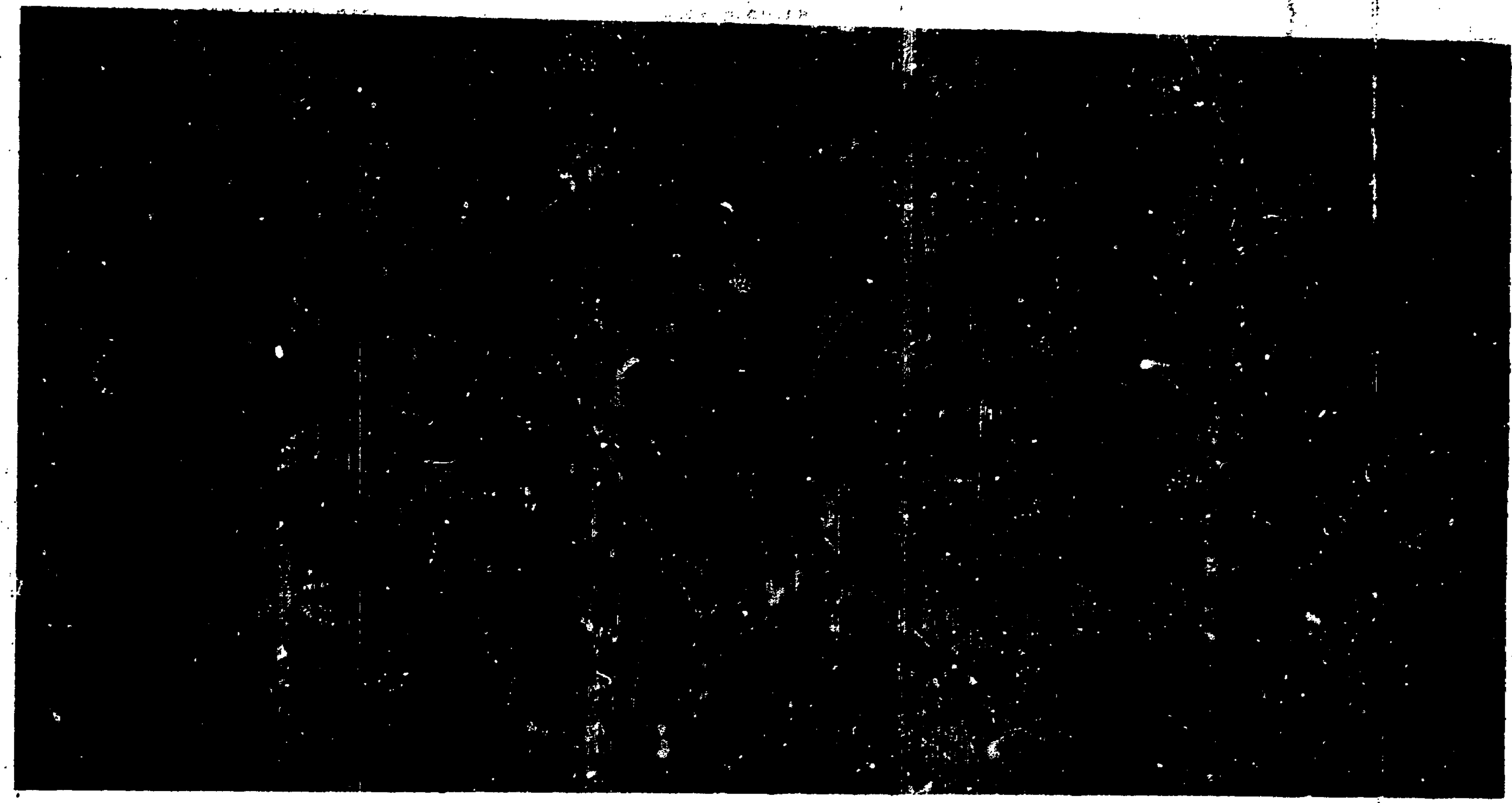


Wind and Dust

Snow Showers

Thunderstorm clouds with lightning discharges

Fig. 10



Recordings of potential gradient from five different stations on same time scale. Check marks indicate arrival of cell over station. Time lag is helpful in providing warning notices.

Fig. 11

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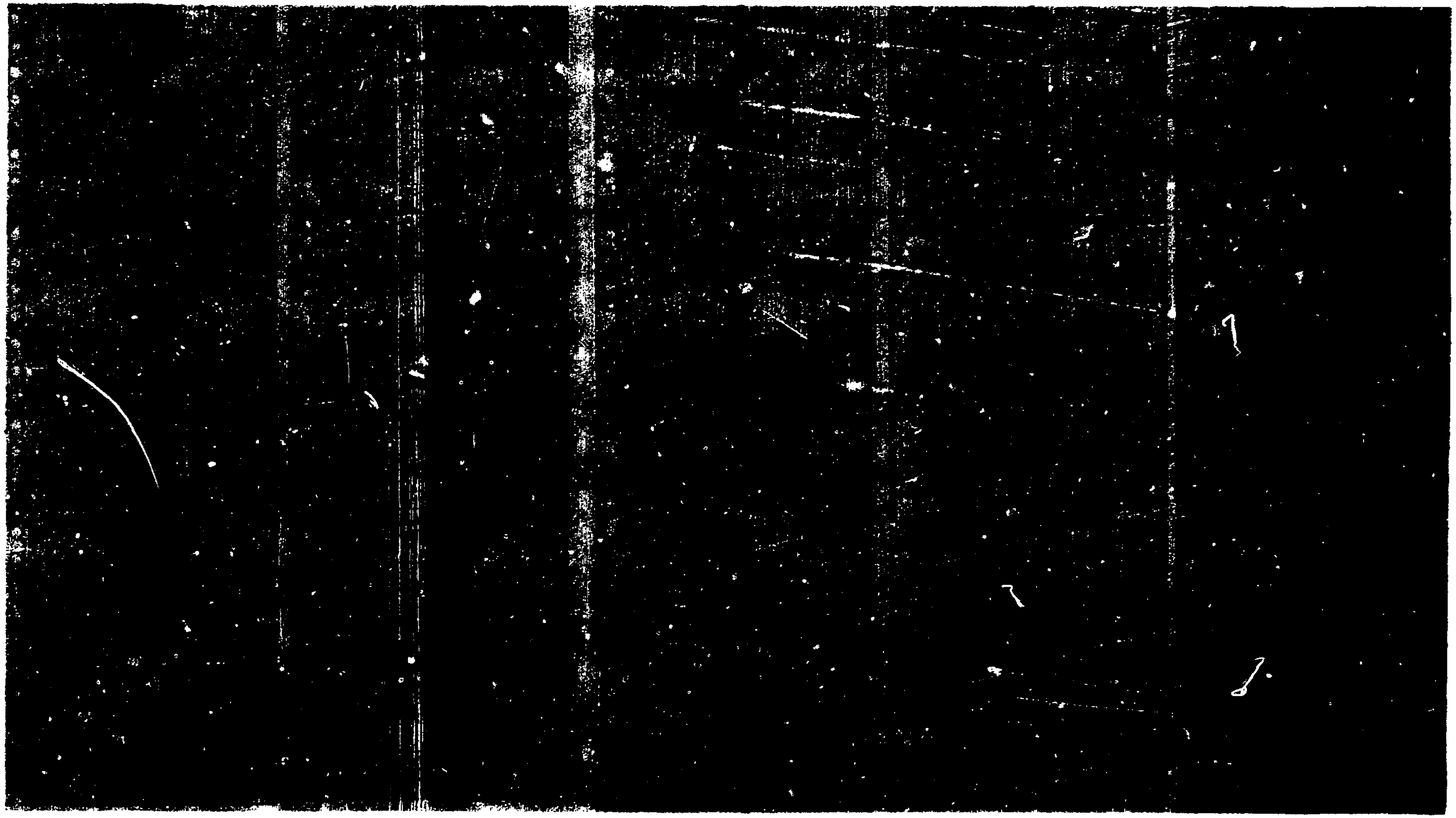

Recordings of potential gradient from five different stations on same time scale. Check marks indicate arrival of cell over station. Time lag is helpful in providing warning notices. Trace 5 indications are from a different family of cells.

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Fig. 12

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SAFETY CONSIDERATIONS IN THE DESIGN OF A VERTICAL MIXER COMPLEX

D. W. Deiters
Thiokol Chemical Corp., Brunswick, Ga.

I. Introduction

In late 1963 and early 1964, Thiokol Chemical Corporation designed and constructed a facility specifically for the purpose of manufacturing very large, monolithic solid propellant rocket motors. The layout of this plant, located on the Atlantic coastline in Southeast Georgia, was predicated on the use of vertical propellant mixers in the production of very large quantities of propellant. The vertical type mixers were selected rather than horizontal mixers because of their improved safety features, and because they are readily adaptable to the high production rates required in the manufacture of rocket motors containing three (3) million pounds or more of propellant.

The over-all plant layout (Figure 1) illustrates the processing philosophy used at Thiokol's Space Booster Division, and should be understood prior to analyzing the safety features that have been designed into the mixer complex having the vertical mixer as the center of activity. Basically, the plant is divided into three areas. First, there is a raw materials storage area that is removed from the processing area by standard quantity distances. The northernmost portion of the facility is devoted to the casting and static test area, the nucleus of which is a pit 52 feet in diameter and 128 feet deep. Then, there is the propellant processing area which includes separate facilities for oxidizer preparation, paste manufacture, propellant ingredient weigh-up, an acceptance laboratory and the mixer complex itself.

While the foremost safety advantage of the vertical mixer is the elimination of the troublesome submerged packing gland that is inherent in the design of a horizontal mixer, an additional safety feature is realized with the elimination of all processing steps from the mixing building except the actual propellant mixing itself. All ingredient weigh-up activities have been removed from this area, as well as those post-mixing activities such as propellant transfer and deaeration. In so doing, possible sources of trouble have been removed from the building, with additional benefit being obtained by eliminating equipment exposure in the event of an incident.

The safety of an operation is greatly dependent upon the people performing the operation. Safety features incorporated in the facility design will not assure a safe operation, but will supplement the safety attitudes of the operators by making their job easier, by providing a series of interlocks which will not allow the process to continue until certain safety checks have been made, and by providing for minimum facility and equipment damage and full protection for personnel involved in the event of an incident.

In designing safety into a mixer facility, there are numerous aspects which must be considered. Among these are the basic processing flow to be utilized, the topography of the plant area, the use of the inhabited building and the quantity distance tables, the type of support equipment required, and the basic design of the mixer itself which would include such things as propellant seals and pressure relief capability of the mixing equipment. In

I. Introduction (Contd)

analyzing the safety features of a vertical mixer facility, this paper will first discuss the facility itself, then will cover the equipment used, followed by a discussion of some of the operational safety procedures employed.

There is a rather unique aspect contained herein following a discussion of safety features incorporated into our facility. It is one thing to design and plan safety features to be employed in minimizing injury and facility damage in the event of a mixer incident, but more importantly, it is necessary to evaluate the performance of these features. As you are aware, Thiokol experienced a mixer fire at Building M-122 in the spring of this year. Because this unfortunate incident did in fact occur, the opportunity has presented itself to conclude with an analysis of the performance of these safety factors.

II. Facility Design

Figure 2 schematically shows the vertical mixer complex which consists of four buildings: two mixer buildings with associated utility areas, a mixer control bunker and a general utility building. The mixer buildings are separated by an inhabited building distance of 1460 feet and an intra-line distance of 320 feet. These distances are those required for 6000 pounds of propellant (Class 9) in an unbarricaded situation. To provide additional safety features, Thiokol used these unbarricaded distances and then added a barricade, thereby providing additional protection against possible damage to adjoining buildings from flying objects or projectiles.

Figure 3 shows the mixer complex during the construction phase. The general utility building, which houses the master electrical switching, the air compressor, and the vacuum pumps supplying both mixer buildings, is of a prefabricated metal construction. Typical bunker type construction was utilized in the mixer control building shown here prior to the positioning of the earth covering. The use of this bunker type construction in conjunction with intra-line distances provides maximum protection for operating personnel in the event of an incident during the mix cycle.

The construction of the mixer building itself is shown in progress in Figure 4. A functional feature of the mixer complex design at the Space Booster Division is the exclusion of all support equipment from within the mixer buildings. The necessary utility equipment, such as hydraulic pumps and hot water systems, is located remote from the mixer building and is protected by re-inforced concrete wall type construction in addition to an earth barricade. The various utilities are piped into the building, thereby providing protection to the support equipment in the event of an incident.

This building, approximately 25 feet wide and 25 feet long, is constructed on a spread footing foundation with pedestals under each load bearing column. These pedestals are interconnected with continuous footings to the foundation wall exterior foundations. Pilings are, of course, utilized where the soil bearings located under the spread footings are extremely low. All foundations extend a maximum of 2 feet below finished grade.

II. Facility Design (Contd)

The basic design of the mixer building calls for a structural steel framework covered with prefabricated panels. This concept provides for minimum restraint to any gases which might be generated, as well as minimizing the size and weight of any projectiles resulting from a mixer incident. The walls of the building are partially enclosed with a 5-ft. high curtain wall of masonry block construction. These hollow load bearing blocks are of standard weight, having a minimum shell thickness of 1-1/4".

The finished mixer building is shown in Figure 5. The structural steel framework shown in the previous figure has been covered with 4-foot by 12-foot prefabricated insulated asbestos cement panels. These panels, basically, consist of rigid fireproof insulation cores approximately 1-1/2" thick, laminated with a waterproof adhesive. Each side of the panel is then covered with a 1/8" thick asbestos cement sheet. This asbestos sheeting is bonded to the insulated core with a waterproof adhesive. The edges of the panels are then sealed for moisture protection prior to installation.

The battens used for sealing both the vertical and horizontal panel joints and for securing the paneling to the building framework are aluminum, sealed with a neoprene weather stripping agent. Additional weather sealing is obtained with the application of a caulking bead along the edges of the battens. This panel and batten system is clamped to the structural framework to permit panel blow-out from an interior pressure of 0. 5 psi.

An exception to this paneling construction can be seen in the blow-out panels and doorways. These wooden frame, pressure relief doors and burnout panels are provided for the immediate venting of any gases generated in the event of a mixer fire. These blow-out panels consist of a dual thickness of 4 mil polyvinyl plastic.

As discussed previously, the mixer buildings are enclosed with an earth revetment to provide additional protection to support buildings within the mixer complex area. Figure 6 shows the construction of this earth embankment. This "U"-shape barricade encloses three sides of the mixer building with the open side facing an uninhabited buffer zone. The use of the wooden framework to support the interior wall of the earth barricade provides for a steep reflection angle of the side of the earth barricade facing the propellant mixer. Figure 7 shows the mixer building with the earth barricade completed. Standard industrial practices were followed in providing lightning protection and grounding protection for each building in the complex.

III. Operating Equipment

The vertical mixers (Figure 8) installed at the Space Booster Division are Baker-Perkins Special Vertical Propellant Mixers, size 18 PRM (Planetary, Revolutionary Mixer). Those portions of the mixer that come in contact with the propellant and associated vapors are fabricated from 304 stainless steel. These include the mixer bowl interior, the blades, and the exposed surface of the upper housing.

III. Operating Equipment (Contd)

The total capacity of this mixer is 600 gallons; the rated working capacity is 420 gallons. This working capacity is that which is measured to within 3/4" of the top of the blades. The basic mix bowl has an inside diameter of 64.0" and depth of 45.5".

This particular mixer, shown again in Figure 9, utilizes a planetary mixing motion. In other words, the mixing or agitating is achieved, not only with the rotation of the blades about their own center line, but with a rotation of the blade shafts themselves about the vertical center line of the mixer. The movement utilized specifies that the outer blade move in a clockwise direction, while the center blade rotation is counterclockwise. Rotation of the blade shafts about the center line of the mixer is achieved with the planetary housing moving in a clockwise direction.

The clearances between the moving parts and the speed of these parts are shown in Figure 10.

The stationary housing of this mixer (Figure 8) is equipped with multiple surface openings required for such things as the addition of curing agent and vacuum lines. Another basic feature of the design of the stationary housing is the nine (9) blow-out ports. These are closed with graphite blow-out discs which are designed to relieve at 5 psi above normal atmospheric pressure. These discs are capable of retaining gasket equivalent seals during normal operations, and, since part of the mix cycle utilized requires mixing under vacuum conditions, must retain full vacuum conditions internal to the mix bowl without failure. These blow-out ports are equipped with restraining rings to cause the discs to fragment rather than become projectiles in the event of a pressure build-up within the mixer bowl. The vent ports are capable of evacuating 3,250 cu. ft. of gas per minute.

The mix bowl is lifted and retained in the mixing position through the use of hydraulic cylinders. This system is equipped with a rapid dumping device for discharging the hydraulic fluid, if necessary, to permit the mix bowl to "free fall" rather than be lowered. This dumping device is actuated by the fire sensing system which permits the discharge of the hydraulic fluid into accumulators located on the bottom side of the lifting cylinders. These accumulators are designed to provide a cushion during the rapid lowering of the mix bowl, but will not restrain this lowering until the bowl is free of the mix blades. As a further safety precaution, a solenoid valve interlocked with the deluge system separates the accumulator from the normal hydraulic system until such time as rapid lowering is required.

The deluge system at the mixer housing is divided into two separate systems: A High Speed Rate of Rise System and a Primac Ultra-High Speed System.

The High Speed Rate of Rise System is one whereby heat actuates a device located at the top external portion of the mixer support structure

III. Operating Equipment (Contd)

which, in turn energizes a deluge valve (Figure 9). With the actuation of this deluge valve, water is directed through external located nozzles against the mixer bowl when in the raised position, and the interior of the mix bowl, or propellant surface, when the bowl is in the lowered position. This particular deluge system will deliver 800 gallons per minute at 40 psi through the wide angle nozzles.

The Primac Deluge System is an ultra-high speed water spray system utilizing photoelectric detectors for actuation in the event of a fire. Basically, there are four detectors mounted in stainless steel tubes which control their field of view. For testing purposes, a small lamp is provided as a light source which can simulate the radiant energy of a fire. This allows systematic checks to ensure that the detector window has not been obscured and that the integrity of the system is sound. Within the mixer control center is a test panel for this Primac Deluge System. It is from this test panel that the continuity of the primer circuit is verified and the capability of the light sensing system can be checked.

The deluge nozzles are located within the annular ring of the mixer housing directly above the mix bowl. These nozzles direct the water deluge against the planetary housing, the mixer blades, and the propellant surface.

The four detectors are located in the same general area as the water spray nozzles. These detectors are arranged to scan the propellant surface during mixing so that a fire will be detected in its embryonic stage. The reaction time from the detection of fire until the actuation of a squib operated deluge valve is approximately 100 milliseconds. The Primac Deluge System is capable of delivering 132 gallons per minute at 40 psi.

IV. Operational Safety Procedures

~~The~~ attention to safety of design of the facility and the equipment is of no avail if the final, most important phase of safety is not critically imposed. This single, most important phase is "Operational Safety Procedure".

Some primary safety requirements are imposed up stream in the system of propellant mixing to assure incident free operation. The thermocouple insert used to monitor product temperature is carefully checked to assure proper restraint. All ingredients added to the mix bowl are screened to preclude tramp metal or objects from entering during the preparatory process. The bowl is then covered during movement to the mixer building as a further preventative measure against foreign matter getting into the bowl.

The mixer control bunker is equipped with three consoles -- one curing agent automatic batch weighing console for each mixer, and a control console from which both mixers are operated.

IV. Operational Safety Procedures (Contd)

A series of indicators on these control panels are designed to signify when a particular phase of the operation is satisfactorily completed. For instance, when the mix bowl has been removed from the road dolly and positioned correctly beneath the mixer blades, a micro-switch is satisfied, giving a "green" go-ahead. The system cannot proceed to the raising of the bowl until this interlock is satisfied, precluding the possibility of raising the bowl until it is clear of the blades.

The mix bowl is manually raised by the mixer crew personnel in the mixing bay until the bowl comes into view on the television monitor at mixer control. At this point, the bowl lift is stopped, and a determination is made that the bowl leveling device is functioning and that the bowl is raising correctly. A final check is made of the mixer housing and the mating bowl lip to assure that they are free of hazardous materials. The mixer lock-out switch is closed by the foreman of the crew as he, being the last crew member, leaves the mix bay area. As the crew evacuates the mixer area, the road barricade is positioned to prevent transients from entering the critical area. In addition to the road barricade, the access road to the mixer is equipped with a flashing indicator indicating live operations are in progress. The flashing lights are turned on at the console immediately upon entering the control bunker.

Tool counts are made at both tool board locations -- at the mixer building prior to leaving the area, and the hand tool board at mixer control. Once these conditions are satisfied, the mixer bowl "raise" lock-out key is inserted into the panel, and the bowl is raised to the seated position on the mixer housing while observing the entire procedure on the television monitor.

In addition to having visual observance of the bowl lifting operation, the facility is equipped with intercom, which permits an audio surveillance during the operation. When the mix bowl has been seated, a green indicator light on the mixer console indicates that the bowl is properly positioned.

With the bowl in position, a "go" condition is indicated. At this point, the operations are interrupted for a Primac Deluge System check. This check serves to establish that materials, dust, etc., have not blinded the deluge sensors. After the check confirms that the deluge system is operable, the Primac master switch is set at the "in-service" position.

The mixing operation is now ready to commence. The mixer control console must be in an all "green" condition before the propellant mixer can start. This insures the bowl to be positioned and aligned correctly, and that all checks have been satisfactorily made. The "personnel in area key" is inserted in the console and unlocks the system so that mixing can commence. A check is made to determine that the road barricades are in position, and that the flashing light is functioning.

The actual mixing operation is started by depressing the automatic cycle button on the console. Immediately, a green indicator light indicates the mixer is in operation. The mixing follows an automated timing sequence

IV. Operational Safety Procedures (Contd)

-- preliminary mixing, cure agent addition, and final mixing.

Upon completion of mixing, the automatic timers stop the mixer, the Primac Deluge System is switched to the "out of service" position, and the mix bowl is lowered until the blades are free of the propellant. The mix bowl "raise and lower" lock-out key is removed, and the "personnel in area" key at the console is removed. This prevents any equipment operations while the keys are in the possession of the crew at the mixer building. The normal operations of removing the mix bowl and positioning a new bowl of materials can take place.

The Space Booster Plant recently (December, 1964) processed a 156-inch motor requiring approximately 840,000 pounds of propellant. This amount of propellant was processed during a 6-day loading period. Of the 155 mixes, 77 were made on one mixer and 78 were made on the other. Of the total 155 mixes made, 2 were rejected -- one because of an excessive addition (out of spec limit) of a raw material; the second because of suspected, or the possible existence of, tramp metal in the mixer bowl. In both cases the mixes were discarded.

During this period, the Space Booster Plant vertical mixer complex was manufacturing finished propellant at the rate of approximately 140,000 pounds per each 24-hour period of operation. This represents the making of approximately 26 mixes of propellant during each 24-hour work period.

The success of this effort is attributed to the constant efficient adherence to the established operational safety procedures.

V. Discussion of Recent Mixer Incident

We have discussed the precautions taken to prevent a fire at the mixer facility, and have covered the design features utilized to minimize damage in the event some unforeseeable circumstance causes a fire, even though these precautions were taken. Such an unforeseeable circumstance caused a fire in a vertical mixer at the Thiokol's Space Booster Division on the 25th of March, 1965.

The cause of the incident has been attributed to the rotating mixer blades making contact with a bulge in the bottom of the bowl, producing sufficient heat either by friction or impact to ignite the propellant. All other contributory items that could have been causes to the incident have been deleted through the course of investigation -- no seal leakage, no tramp metal, no pinched propellant between bowl and housing, etc.

Damage to the installation and equipment was minimal, due in no small way to the attention given to safety features of the facility during the design phase. All equipment involved in the incident was still operable and no injuries were sustained.

V. Discussion of Recent Mixer Incident (Contd)

The deluge system, the construction of the facility, and the safety features all contributed to minimize the severity of the incident.

Figure 11 shows the mixer facility immediately after the incident. The flame and heat sensing elements have reacted properly, allowing the bowl to drop and actuating both the external and internal deluge systems. The blow-out paneling used in the construction of the doors has relieved, and the building panels covering the steel beam construction have been blown away.

Figures 12, 13, and 14 show the building structure after the fire. The building panels have relieved themselves in their entirety, but have not provided any large heavy projectiles. Rapid extinguishing of the fire has limited the damage to a scorching of the paint on the structural beams.

Figure 15 shows the mix bowl in the lowered position after the fire. The castors have been severely damaged upon impact with the floor. The cushioning effect that should have been received from the hydraulic fluid in the accumulators was lost when both accumulators ruptured. The mixer housing has been undamaged, again a tribute to the rapid response of the deluge systems.

It has been ascertained that the bulge in the mix bowl most likely occurred from the freezing of water in the bowl jacket. In addition to providing a means of precluding the possibility of water freezing in the bowl jackets in the future, dimensional safety check of all bowls will be made immediately prior to charging with materials to prevent a recurrence of fire initiation due to the blades striking the bowl surface.

The ultimate in safety would be the designing and operating of a mix facility which precludes the possibility of a fire. Even though the attainment of this goal might seem impossible, it is obvious that the steps taken towards this goal are well worthwhile in that mixer fires are becoming far less frequent, and the resulting damage when they do occur is being kept to smaller and smaller amounts.

Figure 1 - Plant Lay Out

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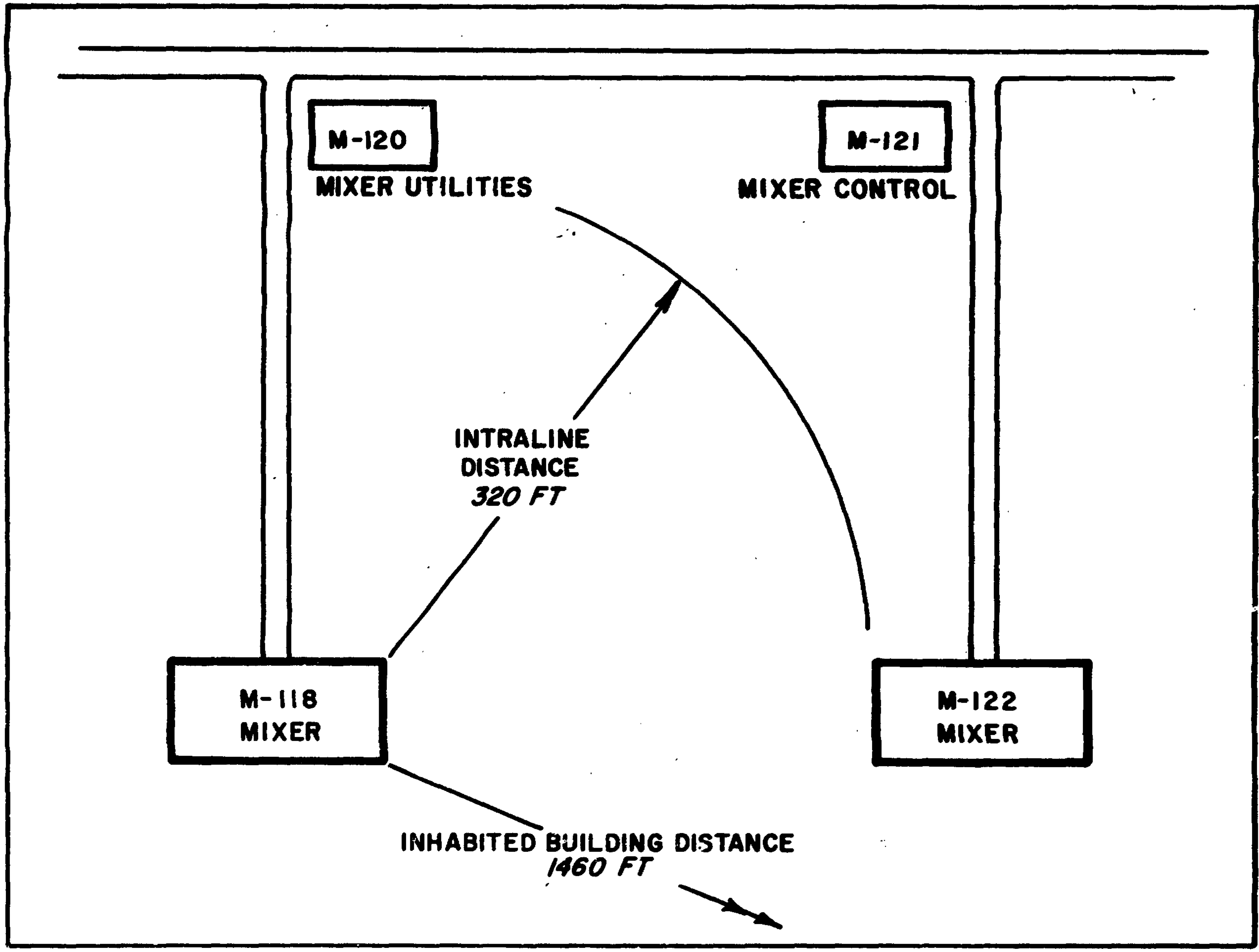

Figure 2 - Vertical Mixer Complex

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Figure 3 - Construction of Mixer Complex

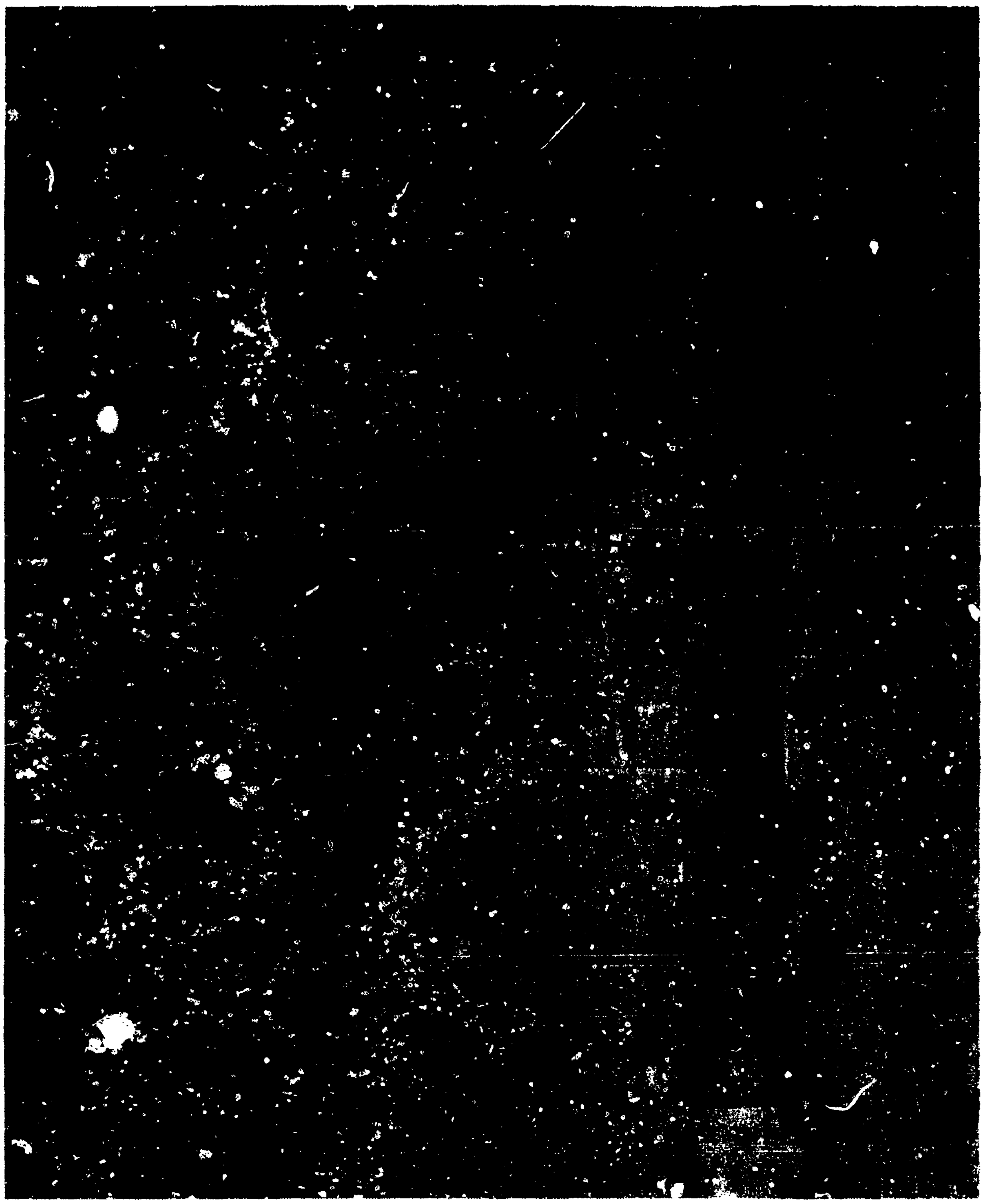

Figure 4 - Construction of Mixer Building

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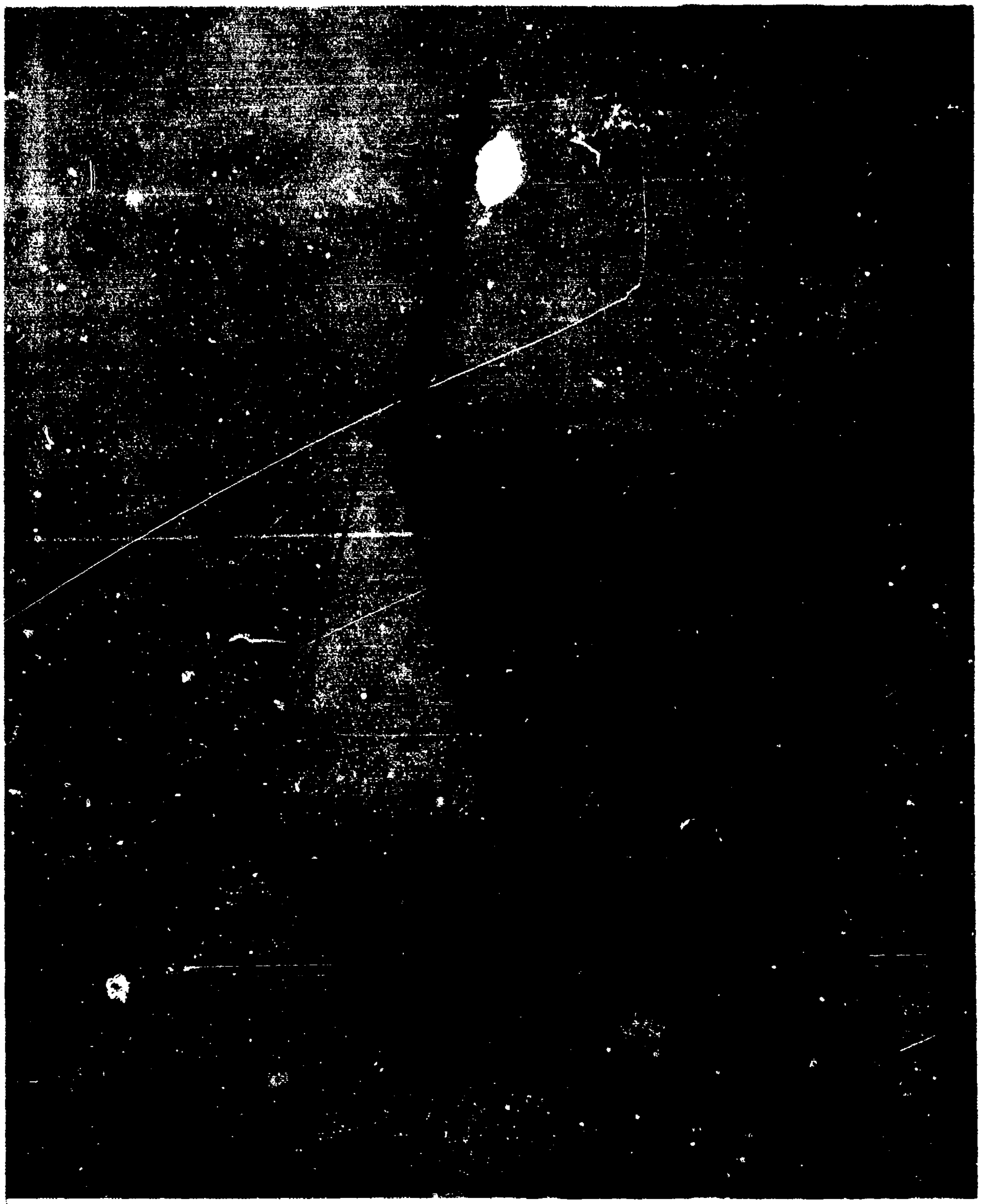

Figure 5 - Mixer Building

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Figure 6 - Installation of Earth Barricade

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Figure 7 - Mixer Building Earth Barricade

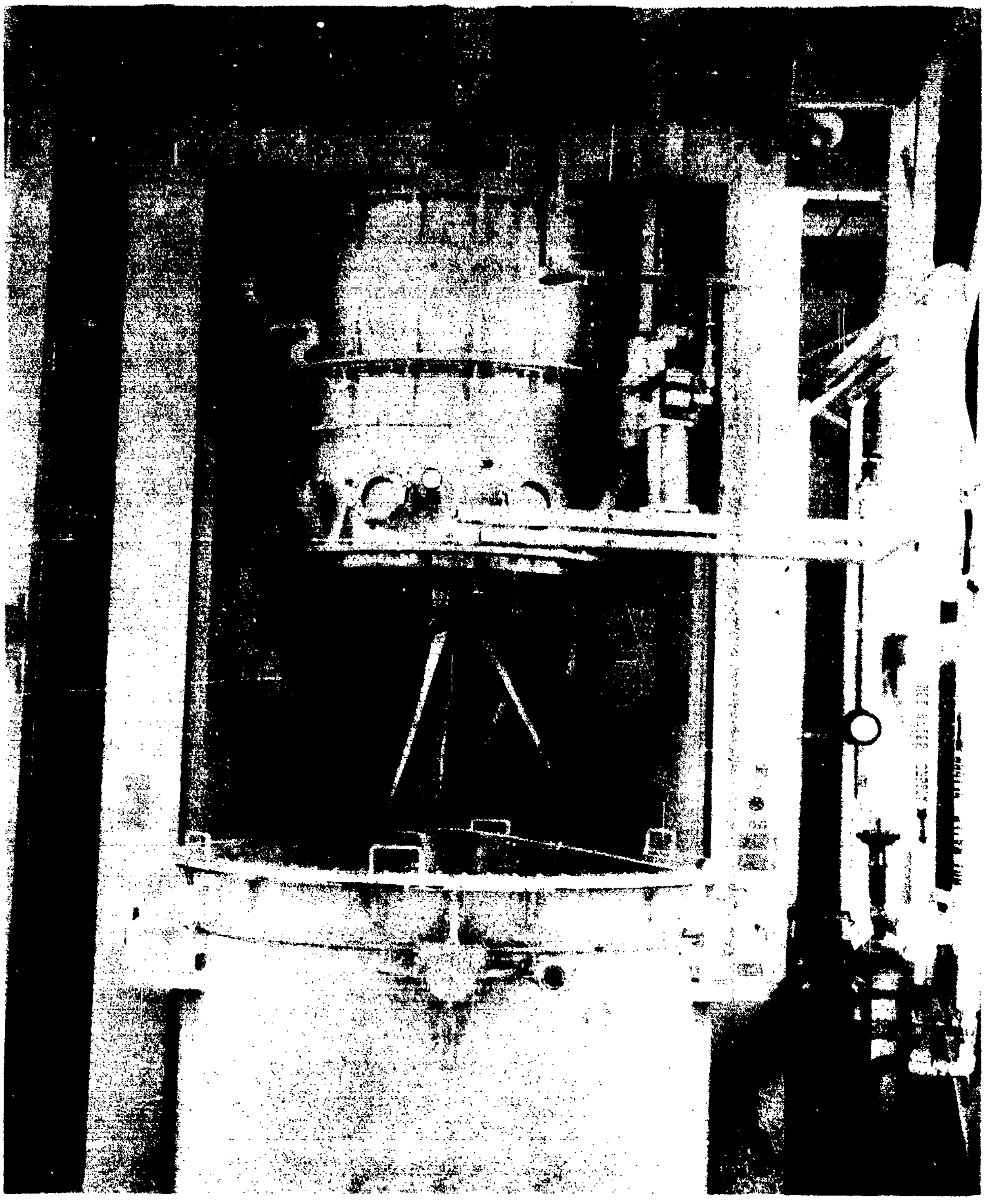


Figure 8 - Vertical Mixer

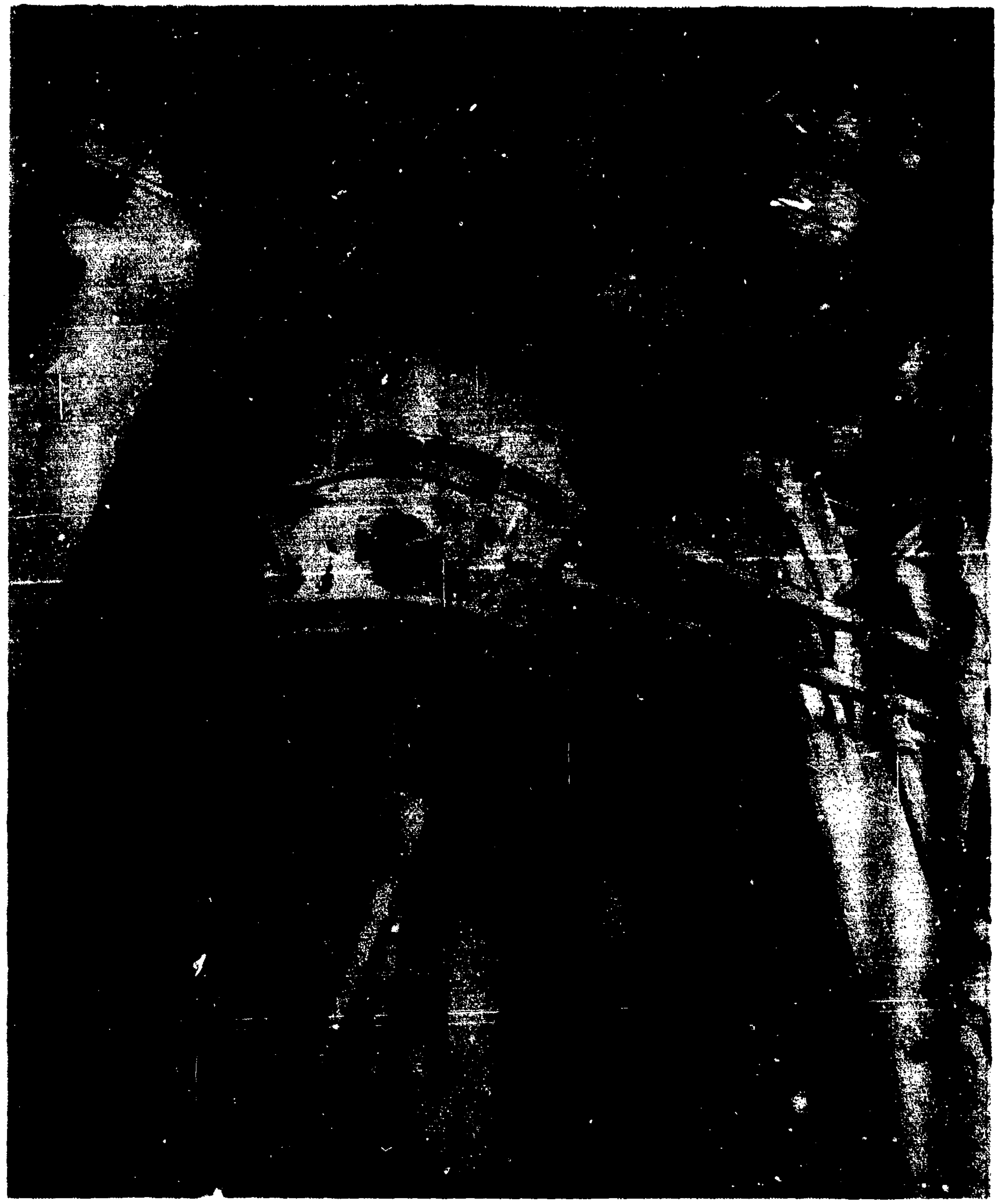


Figure 9 - Bottom view; Vertical Mixer

SPEEDS (RPM)

	High	Low
Motor Drive	72.3	36.6
Outer Blade	45.5	22.75
Center Blade	22.75	11.375
Planetary Housing	15.85	7.92

CLEARANCES (INCHES)

Blade to Blade	0.25 ± 0.010
Blade to Bowl	0.250 Minimum
Blade to Bowl Bottom	0.312 ± 0.063

Figure 10 - Mixer Operating Criteria

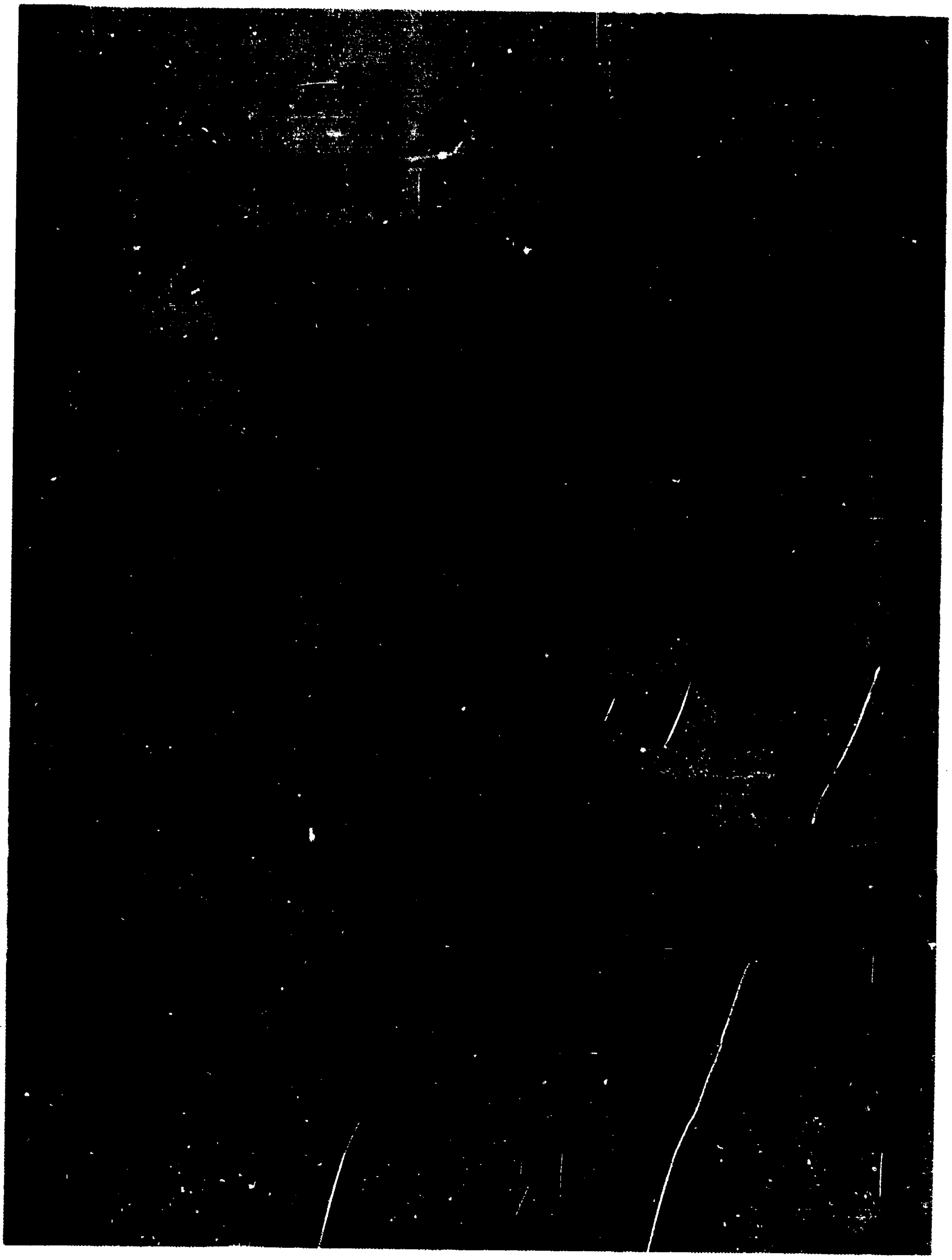


Figure 11

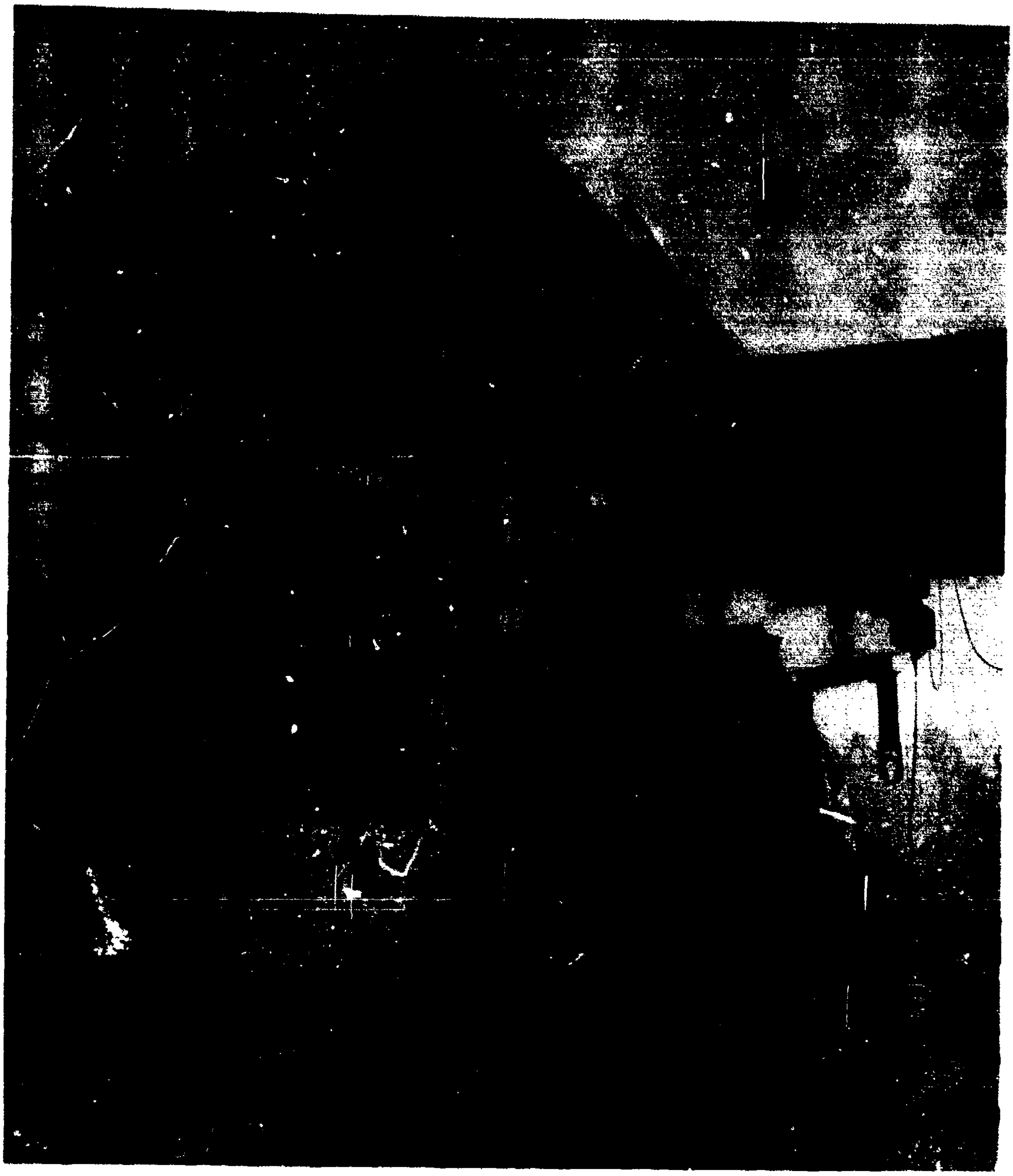
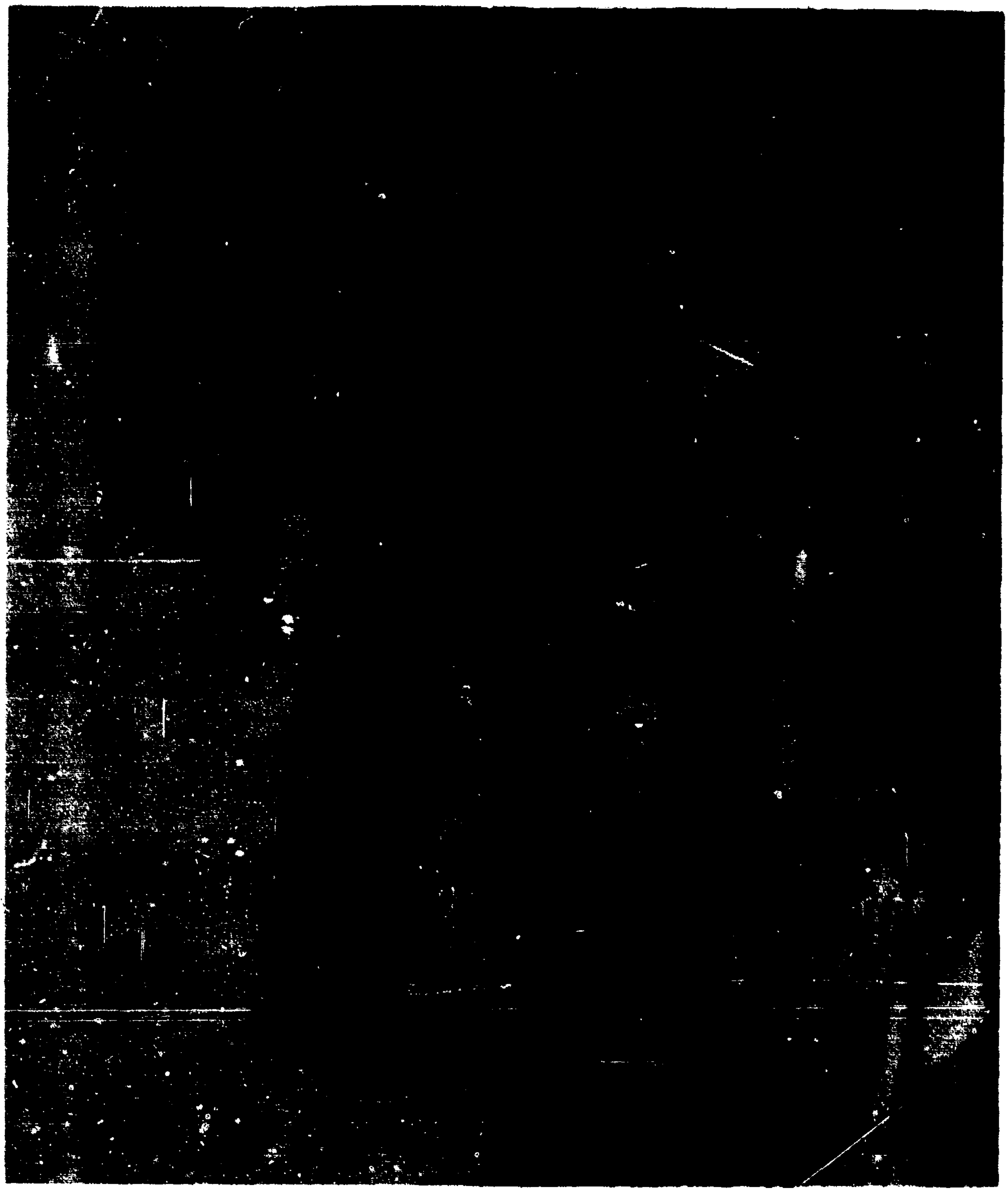


Figure 12



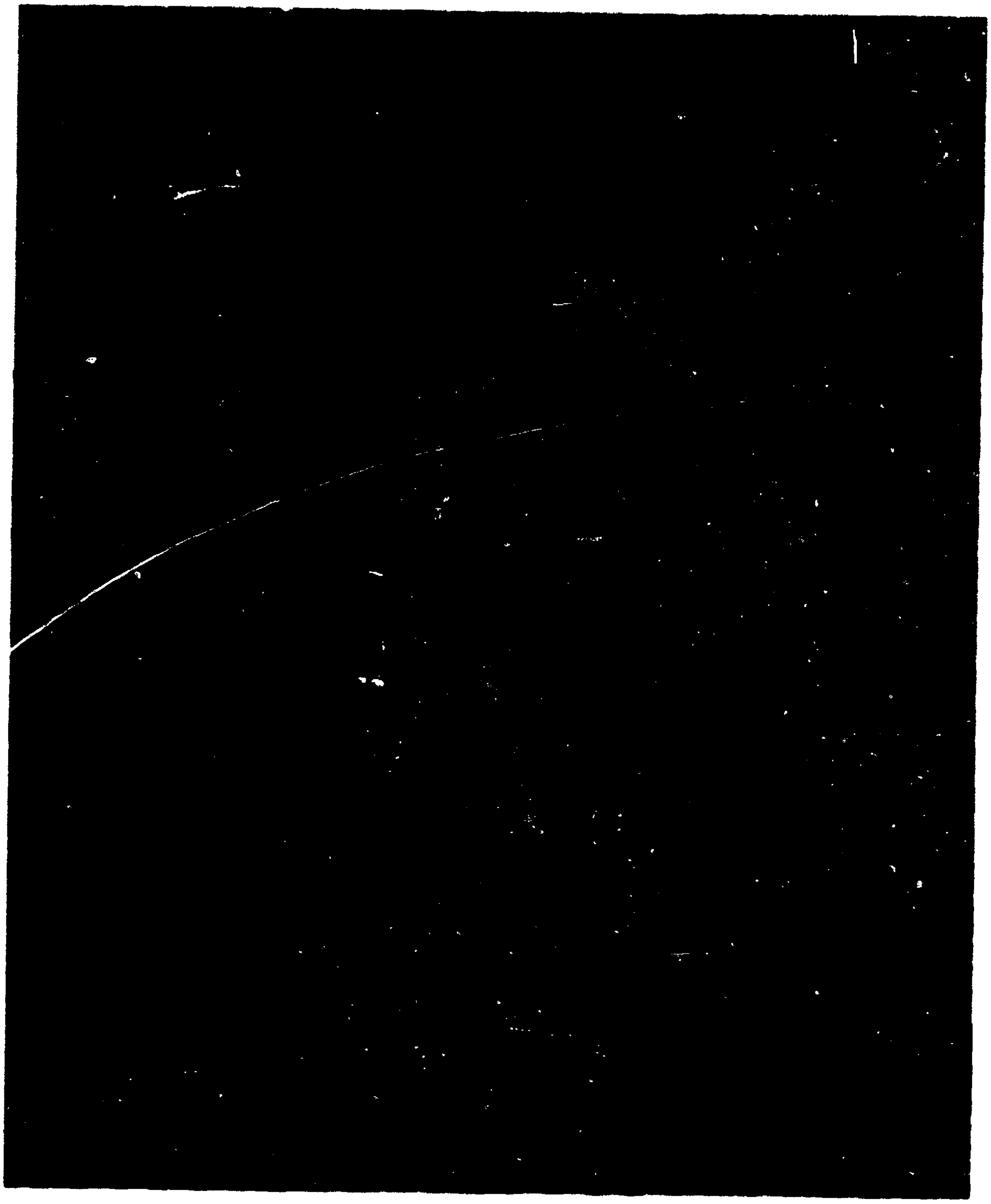


Figure 14

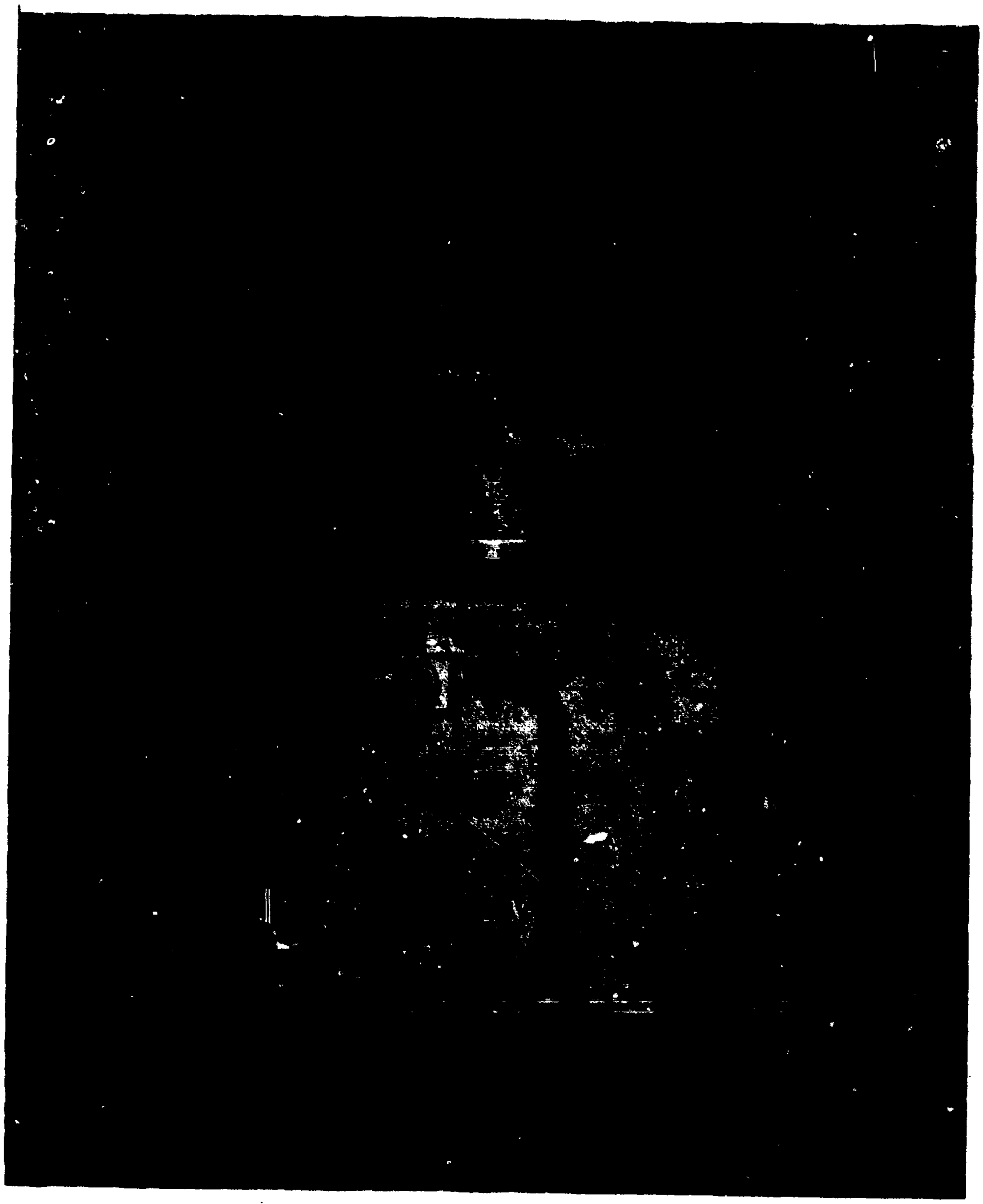


Figure 15

Question not recorded.

Deiters: ...This is a difficult subject for me to talk on. This is the first mixer fire that I've seen that used the Primac ultra-high speed sensing system and I've never seen the damage as minimal as this was. For that reason I attribute it to catching it in the embryonic stage. In other words, before you really had a problem, you had it put out. We did find evidence of paste in the bottom of the bowl that had not burned. There was some molten aluminum, but there was combustible material. I would guess there was 50 to 100 pounds of it in the bottom of the bowl when we drained the water out. That gives you some idea of how fast this system did react. The bowl dropping was quite rapid and I think that really what happened was that we had a real fast reaction which caught the fire in the embryonic stage and then poured the water to it from the external system which kept the heat away from all of the equipment that was in the building itself.

Unidentified: You stated that you determined this was from the freezing of the bowls, because of draining - you've ruled out the stress corrosion cracking and the butt welds?

Deiters: As the cause of this incident, yes, Bob. We are looking at a different welding technique and a different welding material because we have found evidence of degradated wells, but they did not cause this incident. We had a localized bulge which took a real terrific force to have gotten a half inch deflection. So we're sure that this came from freezing water. But also we had a problem with stress corrosion cracking, and we are changing materials. There was some discussion of removing the plug weld and going with the circular fillet weld that can be inspected. Let me speak about the bowl design. Basically the vertical mix bowl is two jackets that are separated by a 3/4 spacer bar. The spacer bar is welded to the inner jacket with a continuous fillet weld which you can inspect. The outer jacket is put in place and attached to this spacer bar with a plug weld. We do not have at our means a fool-proof system of inspecting the plug weld for good attachment and good penetration. This is what I meant when I told Bob there was some discussion of replacing the plug weld with a continuous fillet weld which can allow you then to inspect penetration. But we will change materials.

Unidentified: You are changing your outer jacket material?

Deiters: No, the plug weld material. We're staying with the mild steel outer jacket. We have a mild steel outer jacket, a mild steel spacer bar and a stainless steel inner jacket.

Colitti, Picatinny Arsenal: I'd like to ask a question about the photographs that showed the group of mix buildings that didn't sustain any damage. Could you tell us a little about that construction.

<u>Deiters</u>: It'll be a little. Basically it is a steel framework that has the precast cement panels which we pour molten tar and crushed rock over the top of for a weather sealant. It is not the same asbestos type panels that we have on the sides. Its a heavier type construction.

<u>Colitti</u>: You didn't expect this to blow out on incident?

<u>Deiters</u>: No we didn't and we did sustain some cracks and some leaks. That was the reason we had to replace it. A good question here would be what did we replace it with and I can't answer that, but I can find it out for you though. There's no rock on the tar, cemester board panels is what they put in. The same thing now is on the side, this is the 1 3/4" thick cemester board.

<u>Colitti</u>: I've heard two items mentioned here as far as the primex. I think you mentioned a photo-cell and the gentleman from Lockheed mentioned an ultra-violet light. Isn't it an infra-red system?

<u>Deiters</u>: Its infra-red, yes.

<u>Landau, NOTS China Lake</u>: I was wondering, how do you check the clearances between the blade and the bottom of the bowl and how often do you make this check?

<u>Deiters</u>: We check the clearance between the bottom of the blade and the bowl by putting 3/8" tabs, circular buttons, we attach to the bottom of the blades and we then raise our bowl, pull the vacuum, actuate the mixer and then look at the bowl for any score marks as a result of these marking buttons. The same way we do it from blade to blade. To answer your other question, we formerly did it every six months. We're now going to assist them whereby we check our mixer at the start of each production run, if you will, whether there be two months between production runs or a year between production runs. We will still use the tab systems although in the past we found it was habit forming not to run the mixer but a very short burst of power and let the blades rotate. If you really study the planetary action you get with these blades, it takes quite a few revolutions before any given spot on the bottom of the mix blade will cover the entire portion of a mix bowl so we're going to have to find out a minimum time that we allow the mixer to run.

<u>Landau</u>: Do these tell you the exact clearance you have or do they tell you whether you're hitting or not?

<u>Deiters</u>: No, they give us the exact clearance we're looking for. We have a minimum 3/8" clearance on the bottom of our bowl so these are 3/8" tabs.

Landau: I'd like to point out that at the China Lake facility we've found that the gasket in the upper housing of the mixer actually compresses. We ordinarily run around .150 on the bottom and in our last check we were down to .030. So we're installing some stops in the upper housing to maintain the clearance at all times.

Deiters: I'd like to get with you on what you're doing. We encountered the same problem particularly since we vacuum mix which tends to suck the bowl up. I'd like to get some details from you before you get away.

Landau: One other point, was the bulge in the bottom of the mixer?

Deiters: Yes, in the bottom of the bowl.

Landau: And you have water circulating in that area?

Deiters: We have water circulating at 60 psi. The bowl was hydro-tested to 150 psi before it is delivered to us.

Webb, BuY&D: I'm particularly interested in your comments on the efficiency of the blow-out panels. You indicated that the panel is relieved at a very low pressure. I'm wondering if perhaps you did mean that the panel is relieved at a very high pressure but very early in the time-history of the pressure pulse.

Deiters: There's no question that the rate-of-rise of the pressure within the building is quite rapid, somewhere on the rise the panel is relieved, yes.

Oeinck, Lockheed Propulsion: I stand corrected, it is infra-red. One other question, after the fire was over, was there any vertical play in your shafts?

Deiters: No, none at all.

Oeinck: How about the contamination underneath your seals?

Deiters: There is a double seal system here and our first O-ring seal was contaminated behind the seal, we don't know if it came from the fire itself or the pressure we had at that time or if it was something that had built up there. We had no contamination of the secondary seal at all.

Oeinck: This was in a series of mixes then?

Deiters: Yes. This was the sixth in a series of six mixes as a matter of fact.

<u>Yachnis, BuY&D</u>: How did you determine that the foundations and the structure systems were not affected by the explosion?

<u>Deiters</u>: Basically a visual inspection, our building is a bolted construction rather than a welded construction so we didn't have to dye-penetrant in any of the wells. It was optical for a check for squareness and trueness of the beams themselves, the primary method.

<u>Unidentified</u>: How about the foundations?

<u>Deiters</u>: I can't answer your question, I'm not even real sure we checked the foundations. I know we optically inspected the beams.

DETONATION HAZARDS OF LARGE SOLID ROCKET MOTORS*

Major B. E. Giesler[(a)], O. R. Irwin[(b)], G. L. Roark[(c)], P. K. Salsman[(d)]

ABSTRACT

The results obtained to date on a combined experimental and theoretical program to determine the detonation characteristics of Class II propellant are described.

In the experimental program, the critical diameter of Class II propellant was first reduced to values convenient for practical testing by the addition of various percentages of an explosive adulterant (RDX).. The critical diameter of the RDX-adulterated Class II propellant was determined for several levels of adulteration.

A theoretical model was developed to describe the observed experimental results. The model considers AP grain burning to be responsible for propagating detonation in the RDX-adulterated propellant, with initiation of the grain burning resulting from the "hot-spots" furnished by the detonating RDX particles. The model predicts that the critical diameter of RDX-adulterated propellant should vary as the reciprocal of the cube root of the RDX content. This prediction is in agreement with available data from the experimental program.

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Introduction

The United States is presently developing and testing large solid propellant rocket motors for use in national defense and space exploration endeavors. Because of the large quantities of energetic propellant involved, the catastrophic failure of such a motor is potentially capable of causing vast destruction. A catastrophic failure could be initiated by mishaps such as involvement in fire, impact from some sort of projectile, fall-back during a launch, or exposure to shock resulting from an explosion. Relatively little has been accomplished in the systematic investigation of the hazards associated with large solid rocket motors. These hazards are of grave concern to this country from both a cost and personnel safety viewpoint, especially since an increase in the size and frequency of use of these motors is anticipated in the future. It is necessary that techniques be developed to accurately analyze and predict the hazards and damage capabilities of large solid rocket motors. In the past, explosive hazard evaluation tests were conducted to gain information on particular propellant formulations and applications. When the formulations or applications were altered it was necessary to conduct new tests. The answers to many questions concerning the hazards associated with solid motors were not known, and when doubt existed, they were resolved in favor of more conservative safety criteria. With the advent of the larger solid motors, the cost of "more safety" has become prohibitive.

The Air Force Rocket Propulsion Laboratory, Edwards, California, is presently conducting a Solid Propellant Hazards Study Program, Project SOPHY, to accurately analyze the potential explosive hazards of handling, transporting, testing, and launching of large solid-propellant systems. As an initial effort under Project SOPHY, the Aerojet-General Corporation is presently conducting a combined experimental and theoretical study in order to answer some of the questions concerning one aspect of the overall hazards problem, namely the hazard created by the detonation of a large motor containing a Class II solid-composite propellant.

Existing detonation theories are not directly applicable to the analysis of the detonability of conventional solid propellant motor grains, since they consider the propagation of a steady-state detonation in a solid cylindrical charge, while solid rocket motor grains are normally in the form of cylinders with various shapes of internal perforations. In order to assess the detonation hazards of real motors, the approach taken in the present program has been to first determine the minimum diameter (i.e., the critical diameter) of a solid cylindrical grain that will sustain detonation, and then, by means of a concurrently developed theory of critical geometry, to relate the critical

diameter of the solid cylindrical grain to the critical or minimum size of a given grain geometry that will sustain detonation. This paper is devoted entirely to a discussion of the critical diameter studies of Contract AF 04(611)-9945. The status of the critical geometry studies will be presented at a later date.

Although the critical diameter of conventional Class II solid-composite propellants (i.e., propellants containing ammonium perchlorate oxidizer, aluminum, and an oxygen-lean binder such as polyurethane or PBAN) has never been determined experimentally, available information suggests that it is very large. In the so-called Beauregard Tests (References 1 and 2), solid cylindrical charges of Class II propellant 19 inches and 22 inches in diameter did not sustain a detonation when initiated on one end by a large high-explosive booster. Results of Aerojet theoretical studies conducted prior to Contract AF 04(611)-9945 (Reference 3) were consistent with these experiments in that they indicated that the critical diameter of an ammonium perchlorate-polyurethane propellant was very large ($\sim$ 660 inches).

Since the critical diameter of Class II solid-composite propellants is apparently so large as to economically preclude its direct measurement by full-scale tests, a method is required by which the critical diameter can be predicted from the results of small scale experiments. One approach is to modify the propellant so as to reduce the critical diameter to an economically practical level. There are several possible methods that might be used to accomplish this. For example, previous Aerojet studies have indicated that the critical diameter for porous AP composite propellants decreases as the pore content increases, and approaches the critical diameter of pure low-density ammonium perchlorate ($d_c \cong 1$ - 2 inches) for sufficiently large, homogenously distributed pore contents. The critical diameter of a non-porous solid-composite propellant might then be estimated by extrapolation of the curve for critical diameter versus percent porosity back to zero porosity.

The approach adopted by Aerojet in the present program is to determine the critical diameters of composite propellant samples that have been adulterated with various percentages of a high explosive (RDX). The experimentally determined curve for critical diameter versus adulterant content is used as a guide in the development of a theoretical detonation model which will then be used to predict the critical diameter of unadulterated Class II propellant.

Experimental Program

Test Procedure

The critical diameter tests are conducted with solid cylindrical propellant samples having a length/diameter ratio of 4/1. Detonation is initiated by conical high-explosive boosters (cast TNT) with a height/base ratio of 3/1. The basic test setup consists of the propellant sample, placed vertically upon a steel witness plate, with the booster resting on top of the propellant charge. Detonation of the booster induces a detonation wave in the propellant. The velocity of the detonation wave as it propagates down the test sample is monitored by two rows of pin probes placed along opposite sides of the charge, and by high-speed streak photography. The test setup is indicated in Figure 1. For propellant charges of 100 pounds or less (nominally 8 inches in diameter) the tests were conducted at the Aerojet Chino Hills Ordnance Labroatory. All larger tests are being conducted at the 1-36D Solid Hazards Test Facility of the Air Force Rocket Propulsion Laboratory. This facility can be used for test yields up to the equivalent of 10^6 pounds of TNT. Side-on blast overpressure can be measured at 15 positions, arranged on three radial lines 120° apart (5 positions per line), and face-on overpressure on one radial line (5 positions). The Kistler piezoelectric-transducer and charge-amplifier system is used to monitor all blast data, which is then recorded on a high-speed magnetic tape recorder. The data is played back at a lower speed, to permit an effective time expansion of the data, for recording on a CEC string galvonmeter oscillograph. Heat flux and thermocouple data from the thermal radiation emitted in the large tests is recorded directly on the string galvanometer oscillograph. Documentary and high-speed (Fastax) film coverage is provided on all tests. The layout of the 1-36D Test Facility is shown in Figure 2.

Test Plan

The basic test plan consists in determining the critical diameters of an AP composite propellant in which decreasing levels of RDX adulterant have replaced equal weights of AP. Six test groups with nominal diameters of 2, 4, 8, 12, 24, and 48 inches were chosen to provide experimental data over a considerable range of diameters and RDX contents. The results of the first group of tests, together with a concurrently developed theoretical model, are used to select the adulterant level that will bring the critical diameter within the diameter range of the next group of samples. This process is then repeated for each test group. In the absence of a proven theoretical model to guide the early tests, existing data on the effect of RDX

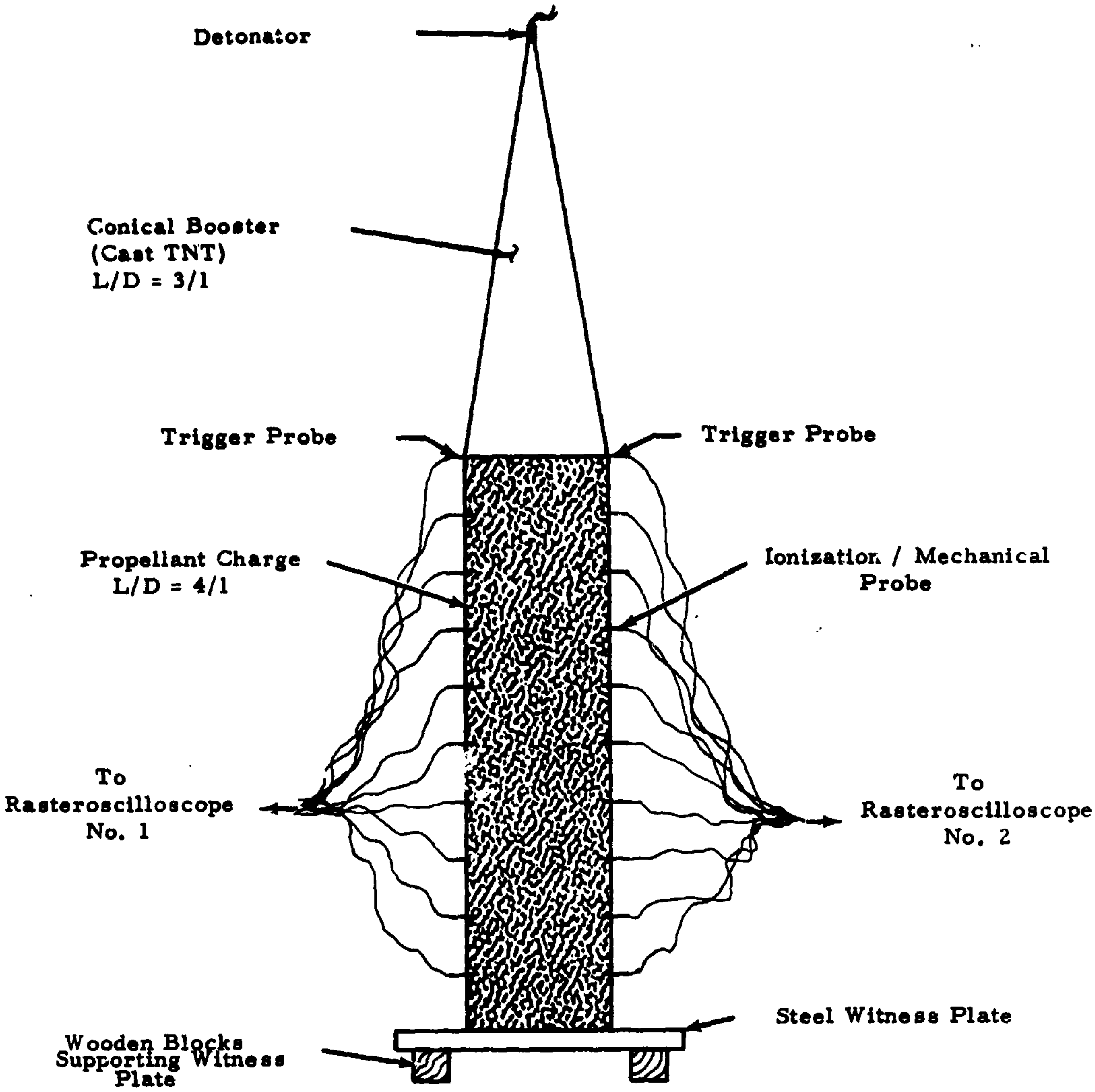
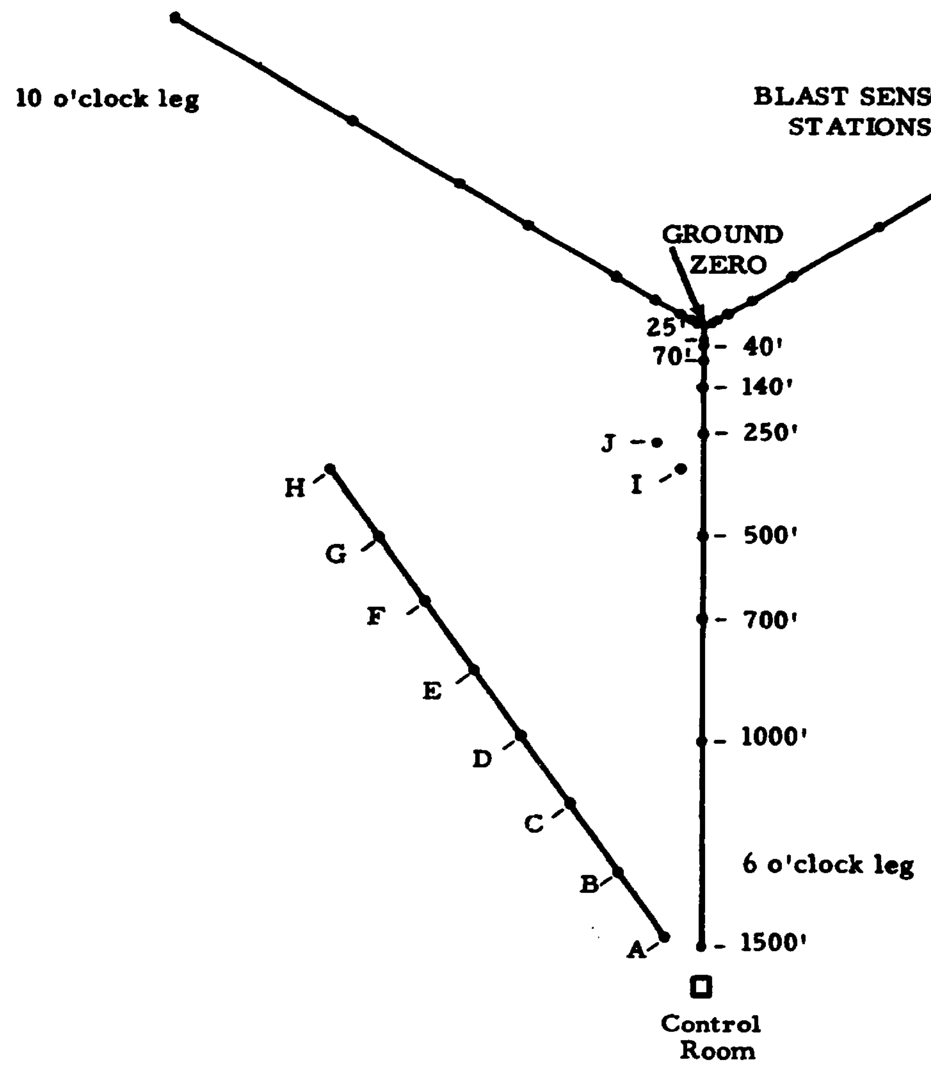


Figure 1 Typical Critical Diameter Test Setup



Camera Station	Camera	Speed
A	Fastax	1000 fps
B	Fastax	4000 fps
C	Milikan	64 fps
D	Flight Research	30 fps
E	Milikan	64 fps
F	Fastax	1000 fps
G	Fastax	1000 fps
H	Fastax	6000 fps
I	Fastax	8000 fps
J	B&W Drum	5000 rpm

Figure 2. Schematic of AFRPL 1-36D Solid Harzards Test Facility.

addition on the critical diameter of an AP composite propellant was used to select an RDX level of 16 wt % for the first test group. The original test plan with the anticipated RDX levels for each group is shown in Table I.

TABLE I

Critical Diameter Test Plan

Test Group	Sample Diameter	Number of Samples	Anticipated RDX Level
1	1-1/4 - 2 in.	32	16 wt. %
2	2 - 4 in.	16	12-16 wt. %
3	6 - 9 in.	8	10-14 wt. %
4	11 - 14 in.	8	8-12 wt. %
5	18 - 27 in.	8	6-10 wt. %
6	48 in.	4	2-8 wt. %

Experimental Results

The rasteroscilloscope records of the probe data and the streak camera records from each test were converted to distance-time information which was then transformed to average velocity data. The criteria for sustainment of detonation was the stabilizing of the velocity of the detonation wave at a reasonably constant value as it traveled down the charge. Although minor fluctuations of the successive data points were usually observed in a sustained detonation, there was no difficulty in distinguishing this behavior from the fading detonation wave in a subcritical sample. In the tests conducted to date, the witness plate results have confirmed the indications of the probe and streak camera records. That is, the sustained detonations have punched sharp-edged, full-diameter holes in the plates while the subcritical samples have caused only gross bending of the plates. Typical detonation velocity data for a sustained detonation and a fading detonation are shown in Figures 3 and 4.

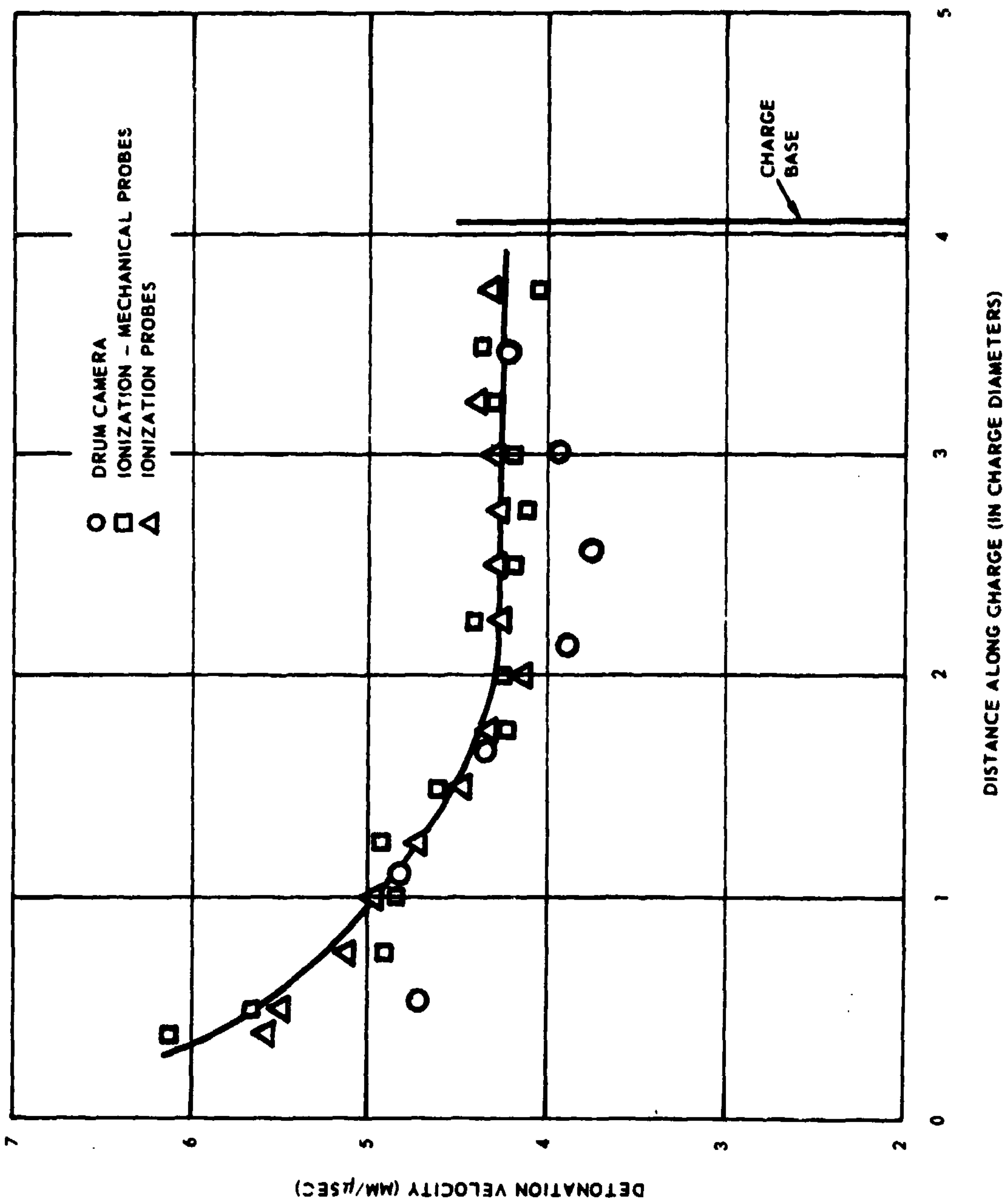


Figure 3 Detonation Velocity vs Distance Along Charge for 8-in.-Diameter AAB-3176 Propellant Charge (6.75 wt % RDX)

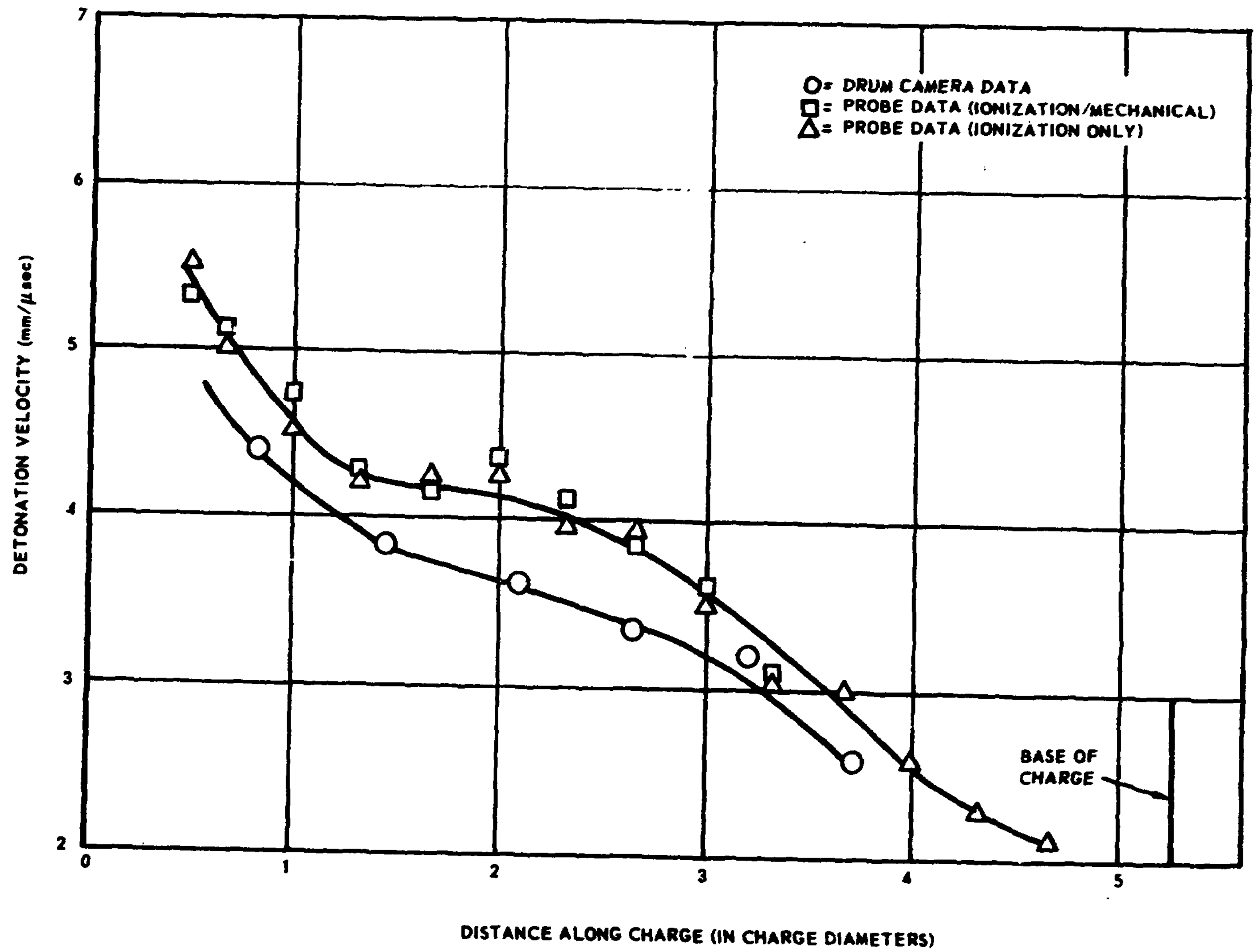


Figure 4. Detonation Velocity vs Distance Along Charge for 6-in.-Diameter AAB-3176 Propellant Charge (6.75 wt % RDX)

Because of difficulties in estimating the percentage of RDX needed to cause the critical diameter of the adulterated propellant to fall within the range of test diameters chosen for each test group, it was necessary to cast and test several sample groups in addition to those shown in Table I. The test results obtained to date are shown in Figure 5.

Theoretical Program

A previously developed theoretical detonation model (Reference 3) considered that the energy release process responsible for propagating detonation in porous propellants was the decomposition of the ammonium perchlorate oxidizer via a grain-burning mechanism (Reference 4) following ignition of the AP by the uniformly distributed shock-heated voids (i.e., hot spots) in a time that is very short compared to the grain-burning time. The total detonation reaction time t is then very nearly the AP grain-burning time:

$$t = \frac{Re}{B} \qquad (1)$$

where Re, the effective grain radius, is one-half the distance between hot-spot initiation sites (i.e., the shock-heated voids) and B is the Arrhenius-type rate expression for the linear pyrolysis kinetics of AP (References 3 and 4). The critical diameter of porous propellant was then calculated by solving Equation (1) in conjunction with an expression derived from the Jones equation for non-ideal detonation (Reference 5), which relates the detonation velocity D of a charge of diameter d to the ideal (maximum) detonation velocity D_i for a charge of infinite diameter, and to the detonation reaction time, t:

$$d = \frac{1.8\,D\,t}{\left[1 - (D/D_i)^2\right]^{1/2}} \qquad (2)$$

As in the previous model for porous propellant, the present "first-approximation" model describing the non-ideal detonation behavior of RDX-adulterated propellant considers that the energy-release process for propagating detonation is also oxidizer decomposition caused by grain-burning, and that the grain-burning process is initiated by uniformly distributed hot spots in a time that is short compared with the grain-burning time. In the present case, the hot spots are provided by the detonating RDX particles. The detonation reaction time is again given by Equation (1),

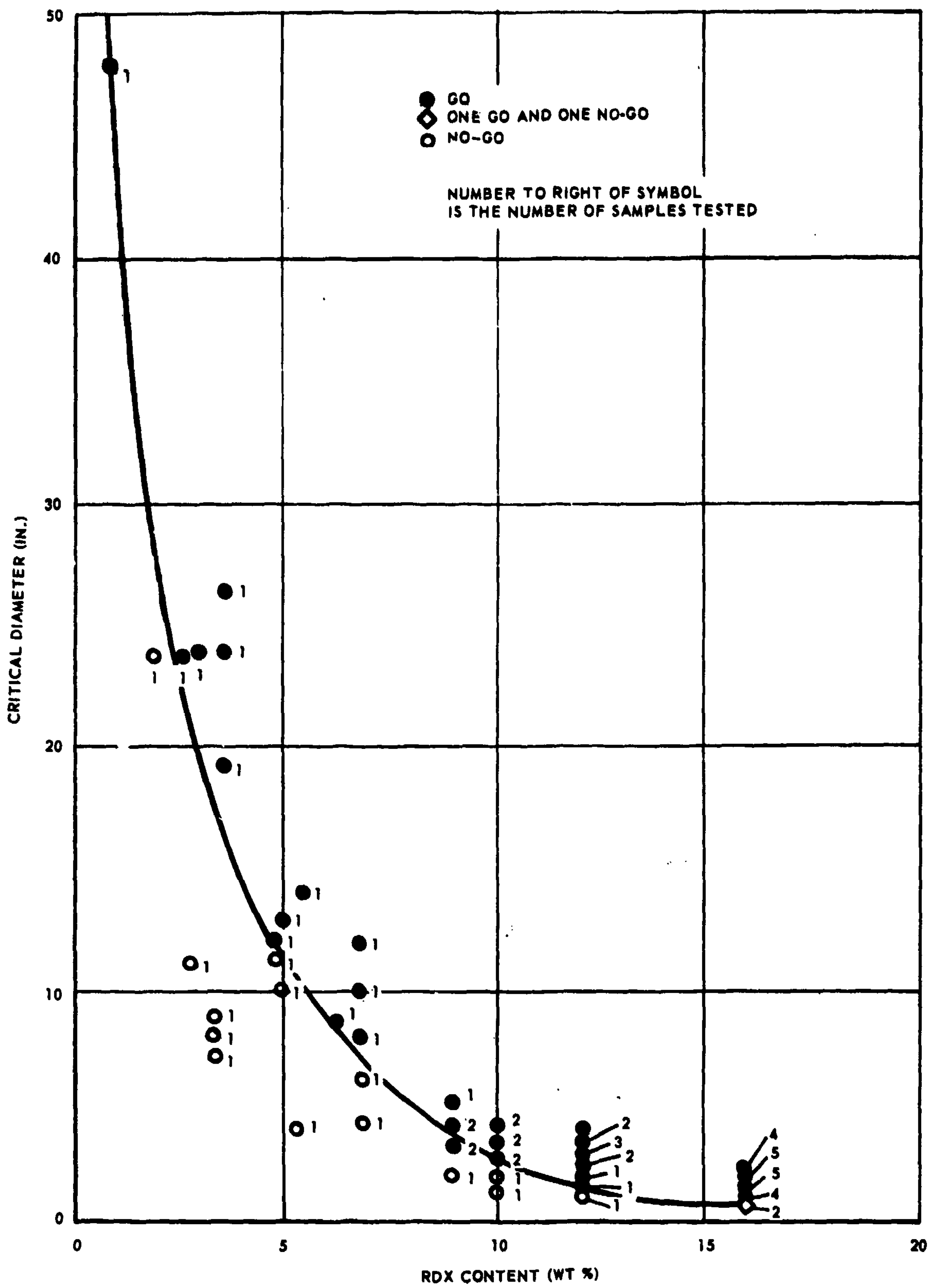


Figure 5. Summary of Critical Diameter Test Results.

except that the effective grain radius can be related, from geometric considerations, to the RDX weight fraction, f, and average RDX particle diameter, d_{RDX}. For the propellants of fixed binder, aluminum, and total oxidizer content (i.e., AP + RDX) used in the present experiments, Equation (1) becomes:

$$t = \frac{Re}{B} = \frac{\frac{d_{RDX}}{2}\left[\left(\frac{0.534}{f}\right)^{1/3} - 1\right]}{B} \qquad (3)$$

which, when combined with Equation (2), leads to an expression relating the effect of RDX weight fraction and particle size on the non-ideal detonation behavior of RDX-adulterated propellant. At the critical diameter this becomes:

$$d_c = \frac{1.8\ D_c \left(\frac{d_{RDX}}{2}\right)\left[\left(\frac{0.534}{f}\right)^{1/3} - 1\right]}{B_c\left[1 - \left(D_c/D_i\right)^2\right]^{1/2}} \qquad (4)$$

If, as a first approximation, it is assumed that D_i and D_c (and therefore B_c, which is a function of D_c) are independent of RDX concentration in the range of RDX contents of interest, then Equation (4) reduces to the form

$$d_c = k_1 \left(\frac{1}{f}\right)^{1/3} + k_2 \qquad (5)$$

where k_1 and k_2 are constants. Equation (5) predicts that the critical diameter of RDX-adulterated propellant should vary as the reciprocal of the cube root of the RDX content. In Figure 6 the available critical diameter data have been plotted in this manner. A straight line, of the form of Equation (5), that passes between the "Go" and "No-Go" data for each test series and that is consistent with "Go" data obtained on the largest tests conducted to date (where "No-Go" information has not yet been obtained) is:

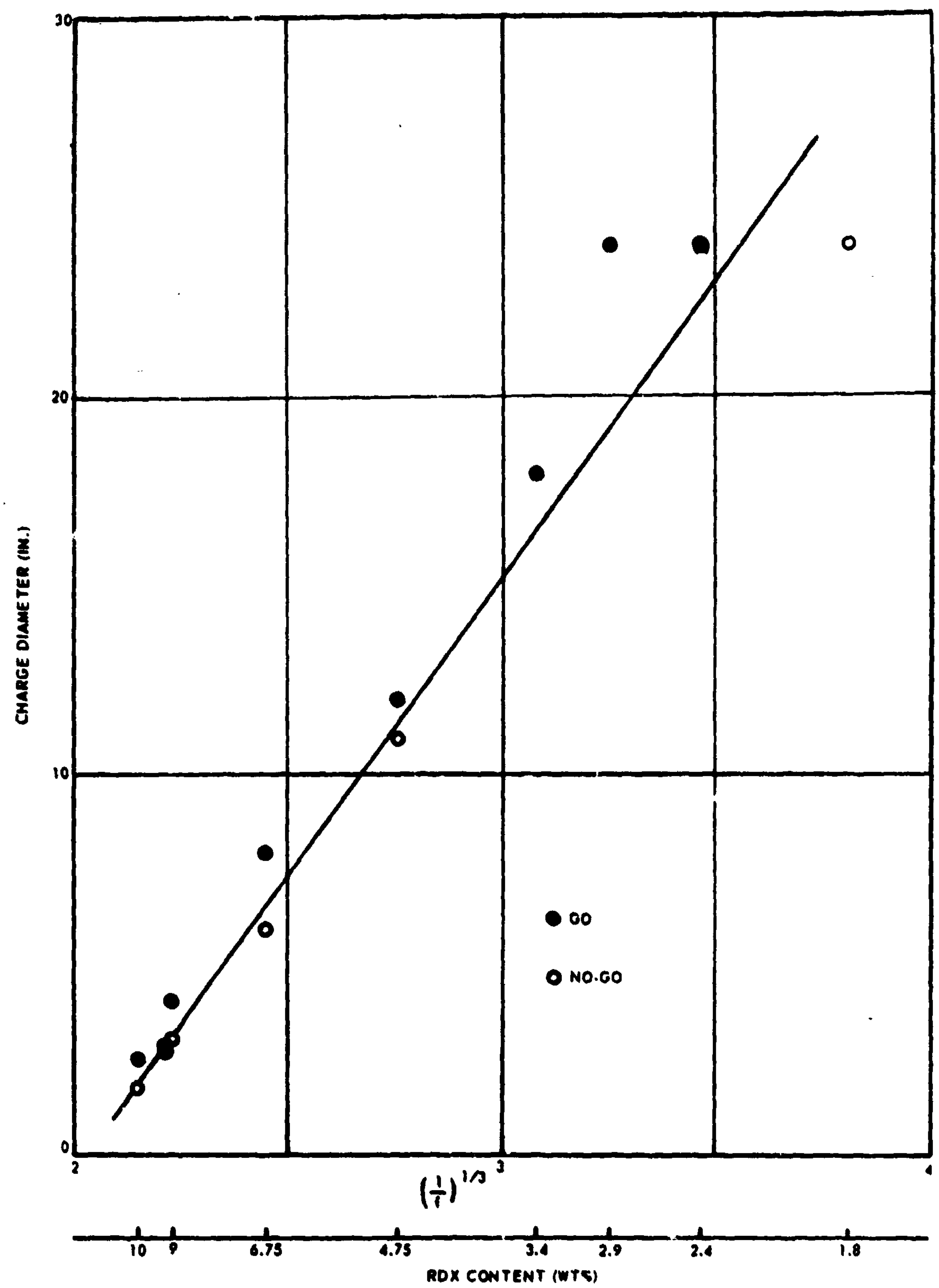


Figure 6. Correlation of Critical Diameter Data Using the Present Theoretical Model.

$$d_c = 15.25 \left(\frac{1}{f}\right)^{1/3} - 30.9 \qquad (6)$$

The results suggest that the present simple detonation model correctly describes the variation of critical diameter for RDX contents between 2.4 and 10 wt %. In order to examine the predictions of the model at lower RDX contents, Equation (6) and the available data were plotted on semi-log paper (Figure 7) and the curve extended to about 0.1 % RDX. It is seen that the critical diameter is expected to increase rapdily as the amount of RDX approaches zero.

It should be noted that the RDX "hot-spot" model of Equation (5) predicts an infinite critical diameter for unadulterated propellant. It is anticipated that, with sufficiently low levels of RDX, the AP grain-burning time will be longer than the time for consumption of AP via a first-order bulk decomposition mechanism. In that case, the RDX "hot-spot" mechanism will no longer be dominant and the detonation reaction time will also depend, through the bulk decomposition kinetics of AP, on the temperature to which the shock-compressed constituents are raised by the detonation wave. Under these conditions, the above model can be combined with the one developed previously (Reference 3), to more realistically describe the events in the reaction zone. Using the combined theory a finite critical diameter for unadulterated Class II propellant can be calculated.

Summary and Conclusions

This paper has presented the results of the critical diameter experiments performed to date on Contract AF 04(611)-9945, and described a theoretical detonation model consistent with these results. Data from the remaining tests and further refinement of the theoretical model will provide a more realistic estimate of the critical diameter of Class II propellant.

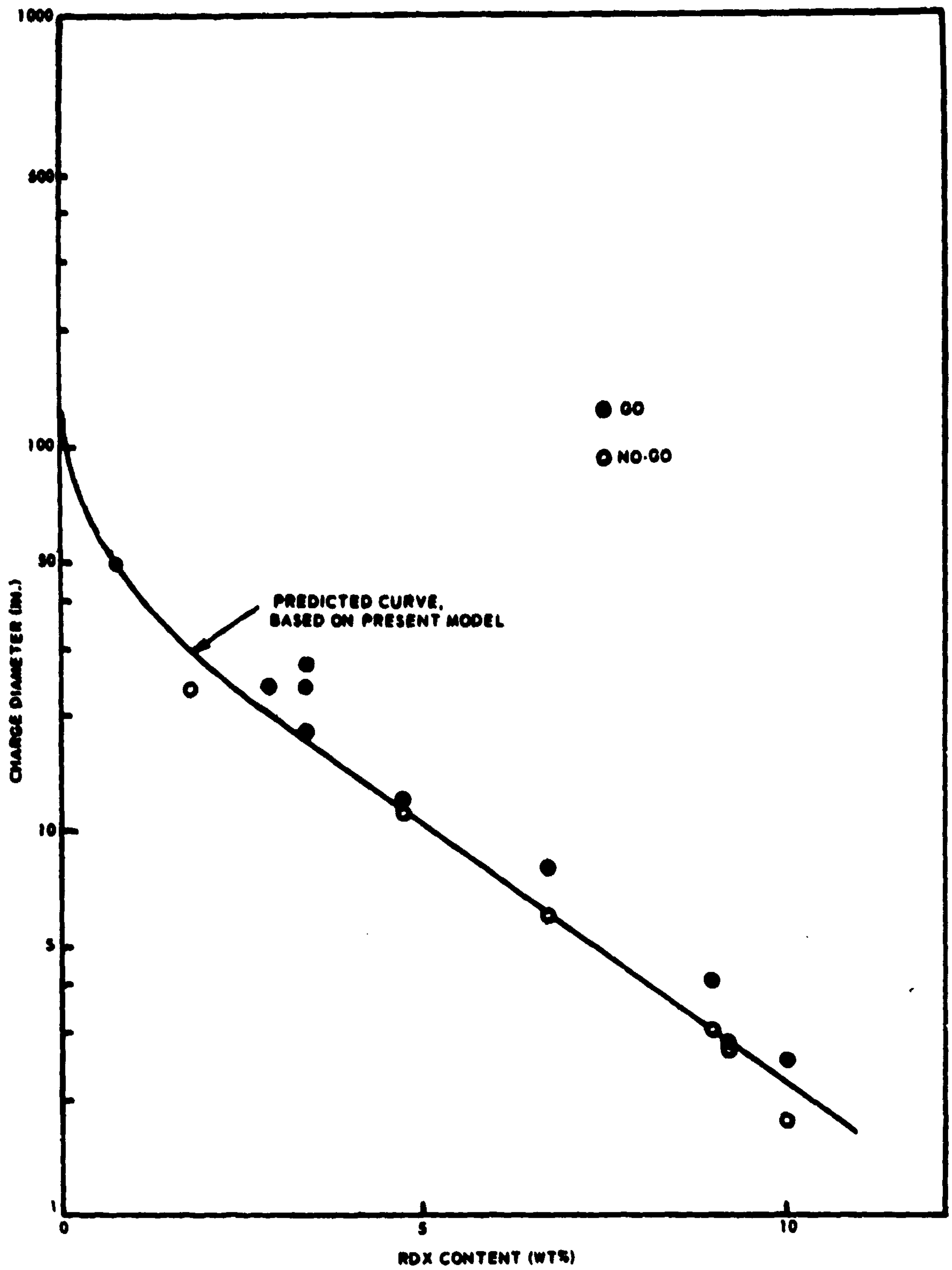


Figure 7. Extrapolation of Present Theoretical Model to Lower RDX Contents.

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Harton, NASA Hq: I was wondering why you used TNT donor in place of pentolite inasmuch as the minimum test criteria called for pentolite. Did you have any particular reason for that?

Giesler: Yes, there were several reasons, one of which was the availability of the TNT. The contractor was able to use this without any problems. We had to cast it in quite large quantities and we definitely wanted to overboost the acceptor. We were not interested too much whether the initial shock wave varied to some extent. This was not a criteria for the initiation study on this portion of it.

Cole, BRL: You may not be overboosting that, you show a detonation velocity of about 5.8.

Giesler: That's probably correct on that one.

Cole: That's pretty low unless you got awful low density TNT, so that if you use pentolite you'd be sure that you were overboosting your charge.

Giesler: No, I think if you look at those slides again you'll find that the first velocity was up around 7,000 meters. Remember the first velocity that we've shown is close to the TNT and the stabilized velocity was that due to the test article.

Oberholzer, SSD: I'd like to ask you if you plan from these geometrical analysis you're going to make of equating a TNT equivalency to large solid motors that are less than the critical diameter?

Giesler: One of the results that we are getting from this program is the determination of the actual pressures on these sub-critical test results. In this particular case since we're interested in the detonation primarily we're not using them in our present contract. However, we are recording this information from all of our sub-critical test articles, and later we'll be able to use it to come up with some of these answers. But we do not have a special program to test sub-critical test articles. We don't really think its going to be necessary at this time.

Oberholzer: Do you think this is going to be valid to apply to the composition of propellants?

Giesler: Yes I do. There was some question at first on what the RDX would do to the propellant on this detonation. However, since the program was set up so that we used decreasing amounts of the RDX, as we proceeded this factor would become smaller and smaller and I think as you'll note from the test results that our doubts have been alleviated. I don't think we're going to have any problems this time

coming up with good valid answers. I feel very confident the farther we move along in the program about the validity.

Perkins, ASESB: May I respectfully interject that that is Maj. Giesler's opinion and I think that as far as the critical diameter is concerned perhaps its very true, but I don't think this has any real relationship yet to what may be termed high explosive yield for the test vehicle involved and that we hope we can get some more information on this score.

Landau: Just watching the film I got the feeling that the operation you were doing wasn't exactly very safe. You're drilling holes into very large charges and men are standing all around without any precautions. Am I being overcautious or do you feel that this is the case also?

Giesler: All I can do in this particular case is direct you to the Aerojet-General Corp. because they are the ones conducting the test, but they are required to comply with safety requirements.

Perkins: The Armed Services Explosives Safety Board has been nibbling away a bit at this subject in the particular area of "high explosive yield" of large masses of solid propellant and we have with us today Mr. H. M. Richey of the Naval Ordnance Test Station, China Lake to describe briefly to you the preliminary results of this program.

HIGH EXPLOSIVE YIELD TESTS OF SOLID PROPELLANTS

Harold M. Richey
U. S. Naval Ordnance Test Station
China Lake, Calif.

As part of a continuing program to analyze and predict the damage capabilities of solid propellant rocket motors, a series of blast tests was conducted at the U. S. Naval Ordnance Test Station at China Lake, California, during the period November 1964 to March 1965.

These tests - held under the auspices of the Armed Services Explosives Safety Board, and funded by NASA were designed to evaluate the explosive hazard characteristics of solid propellant rocket motors. The test motors were provided by the U. S. Navy Special Projects Office.

This was accomplished by assessing the blast yields of two classes of solid propellant formulations when subjected to severe explosive shock and then comparing these yields to that produced by a standard explosive.

The propellants tested were: a class 7 double-base, and a class 2 polyurethane composite. The test articles were Polaris motors, and for most tests, the explosive stimuli was provided by placing 96 pounds of C-4 in the grain perforation. This phase of the test program consisted of seven tests involving class 2 and class 7 solid propellant motors, singly and in combination and a calibration test using 10,260 pounds of Composition B. It was predicted that this quantity of Comp. B would yield overpressures midway between the extremes expected from the solid propellant tests. (Figures 1 and 2)

The instrumentation used to obtain overpressure data consisted of three types of gages 1) the model PHS, BRL self-recording mechanical gage 2) the model PNS, BRL self-recording mechanical gage and 3) the Kistler piezoelectric gage. These instruments were placed along two radial lines which were 90 degrees apart, and were oriented to obtain side-on overpressure data. To provide redundancy, two instruments were placed at each station except those closest and farthest from ground zero. (Figure 3)

Because of the differences in response times, the Kistler gages were placed relatively close to ground zero, the PNS gages at mid positions, and the PHS gages at the more distant locations. Testing began with the calibration firing.

Cans containing the explosive were arranged in a configuration which approximated the geometry of two test motors in a side-by-side position. (Figure 4) Two cans were removed and placed on top of the

pile and forty-pound booster charges were then inserted. Two electric blasting caps were attached to each charge.

The explosion produced two distinct shock waves as shown by the blast gages and a crater 52 feet in diameter, approximately nine feet deep. Overpressure data, particularly that nearest ground zero, tended to exceed predicted values based on standard TNT curves. However, since the data recorded along both radial lines were in close agreement, it was assumed to be valid.

In the first of the following tests a motor containing 7,250 pounds of Class 2 propellant was used. (Figure 5) The primer was placed in the grain perforation, and into the cavity where the nozzle chamber joins the grain perforation. A large number of burning and non-burning fragments were thrown to either side of the motor for a distance of about 3,000 feet. The resulting crater was 13 feet in diameter and 3 feet deep. (Figure 6)

In this test, 7,250 pounds of class 2 propellant produced a yield equal to that produced by 2,330 pounds of TNT, or about 32 per cent of equivalent weight of TNT.

In the second test, two class 2 motors were placed side-by-side. (Figure 7) Ninety-six pounds of C-4 was placed in each motor. The explosion of these two motors produced a crater 20 feet in diameter, and 2½ feet deep. In this test, 14,500 pounds of primed class 2 propellant produced a yield equal to that produced by 6,530 pounds of TNT or about 45%.

A class 7 motor containing 7,360 pounds of propellant was used in the third test. The primer was placed in the grain perforation. No fragmentation was observed, and only small motor case fragments were recovered. The resulting crater was 36 feet across and 7 feet deep. (Figure 8) In this test, 7,360 pounds of primed class 7 propellant produced a yield equal to that produced by 10,550 pounds of TNT or about 143%.

In the fourth test, a class 7 and a class 2 motor were positioned side-by-side. The class 7 motor shown on the right was primed with 96 pounds of C-4. This test was repeated to confirm the data. (Fig. 9)

In both tests, the class 7 motor exploded completely and left no propellant fragments. The class 2 motor produced burning fragments and chunks of unburned propellant. The craters were about 52 feet in diameter and ten feet deep. (Figure 10)

In these two tests, the propellant weight was 14,610 pounds. The yield, in terms of TNT equivalency was 17,000 pounds or 116 per cent in test number four, and 15,500 pounds of TNT or 106 per cent in test number five. The burst symbol indicates the primed charge.

In the sixth test, a class 7 motor, which again functioned as the donor, was placed on top of a class 2 motor. (Figure 11)

The resulting explosion and fragmentation was similar to that which occurred in the two previous tests. However, the crater was much more shallow and shaped more like a dish. The diameter was 60 feet, with average depth of 2 feet. A small cone-like depression, about 5 feet deep was found in the center. The largest fragment of unburned propellant recovered weighed one pound, and was located about 1,000 feet from ground zero. The results of this test were almost identical to those obtained in test 5.

In the final test of this series the class 2 and class 7 motors were positioned the same as in test no. 6; however, the class 7 motor was primed externally with a 100-pound spherical charge of cyclotol. (Figure 12) This change in the primer position was made to further investigate the effects of donor - acceptor geometry. The explosion appeared about the same as that in test no. 6 and the fragments and resultant crater were identical. The overpressure was equal to that produced by 15,500 pounds of TNT or about 106%.

Examination of the data shows that the TNT equivalent yield for class 2 propellants tested alone was less than 50 per cent (Chart #1), while class 7 propellants tested alone produced a yield of almost 150 per cent (Chart #2). The tests of class 2 and class 7 propellants in combination produced yields of approximately 100 per cent. Apparently the changes in geometry in these tests had no significant effect on yield.

Although Polaris motors were used, the data obtained should be regarded as having general application for H.E. yield in propellant quantity-distance work and not for the establishment of H.E. equivalency figures for any specific weapon system.

Additional tests of other solid propellant formulations are being planned for the next phase of this program in which the effects of geometry and differing explosive stimuli will be examined. This work - being done at the U. S. Naval Ordnance Test Station, at China Lake, is part of a continuing effort to develop and improve explosive safety criteria.

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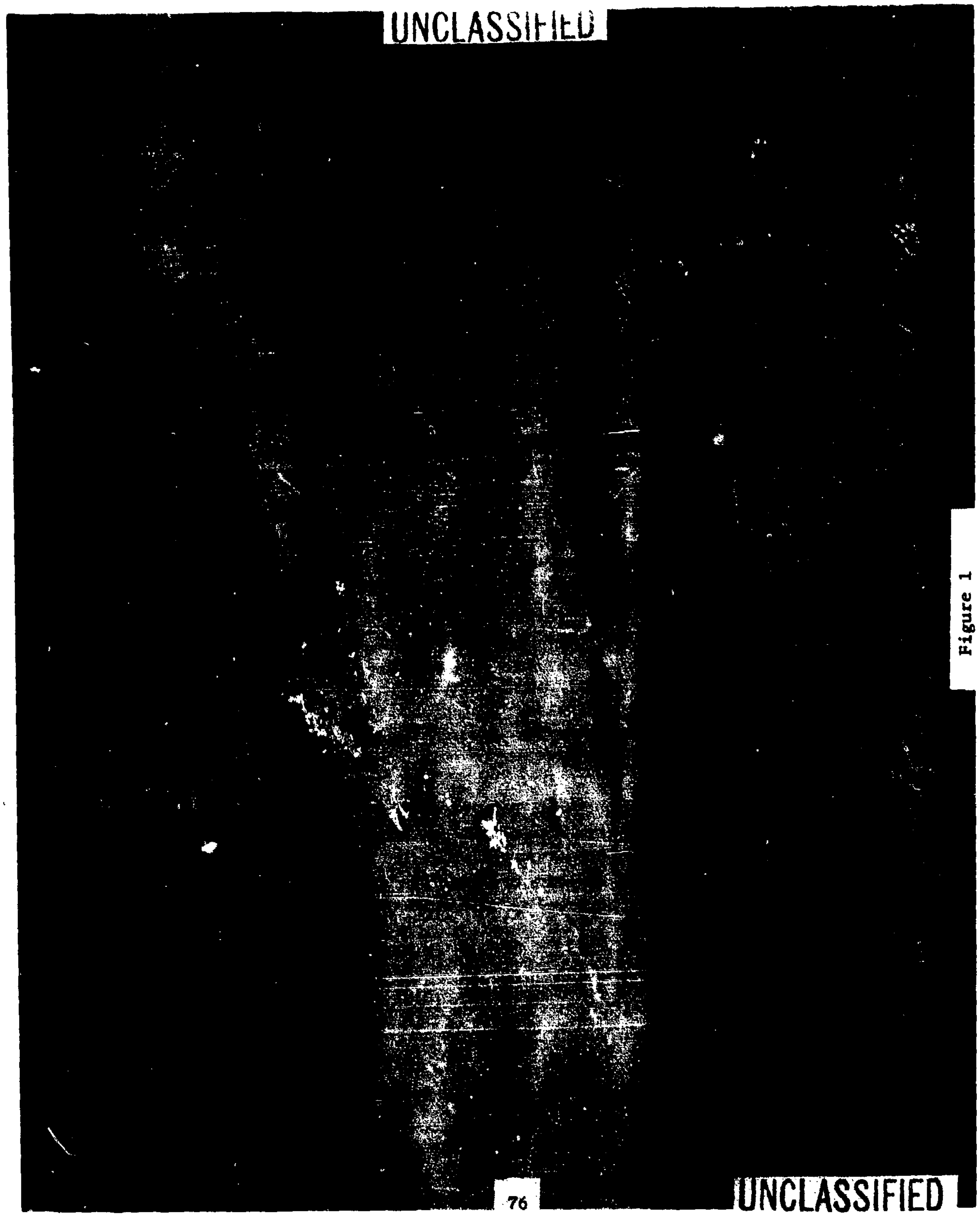

Figure 1

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Figure 2

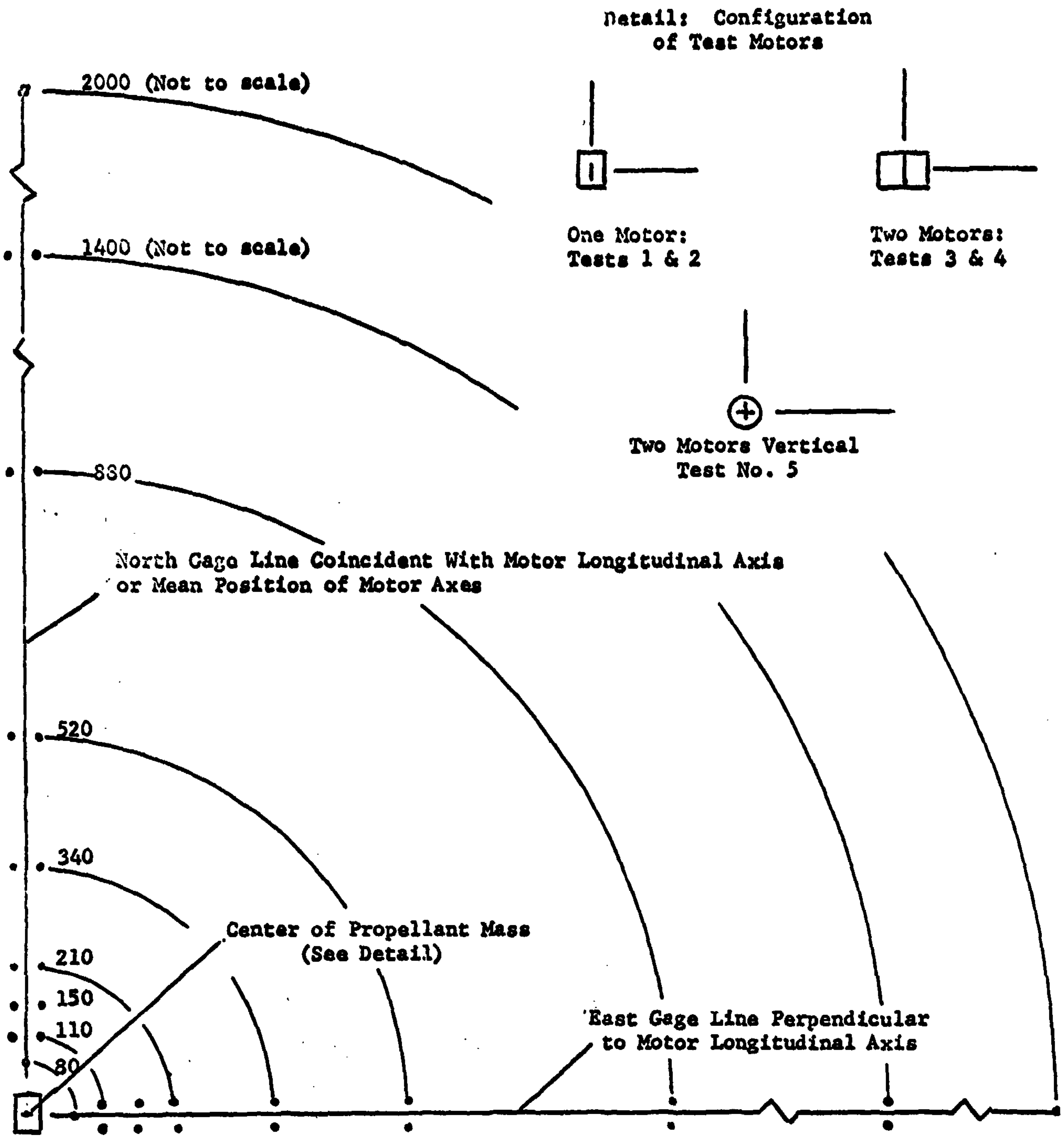

Fig. 3 Overpressure Gage Layout for Motor Hazard Tests Using 1 or 2 Motors Per Test

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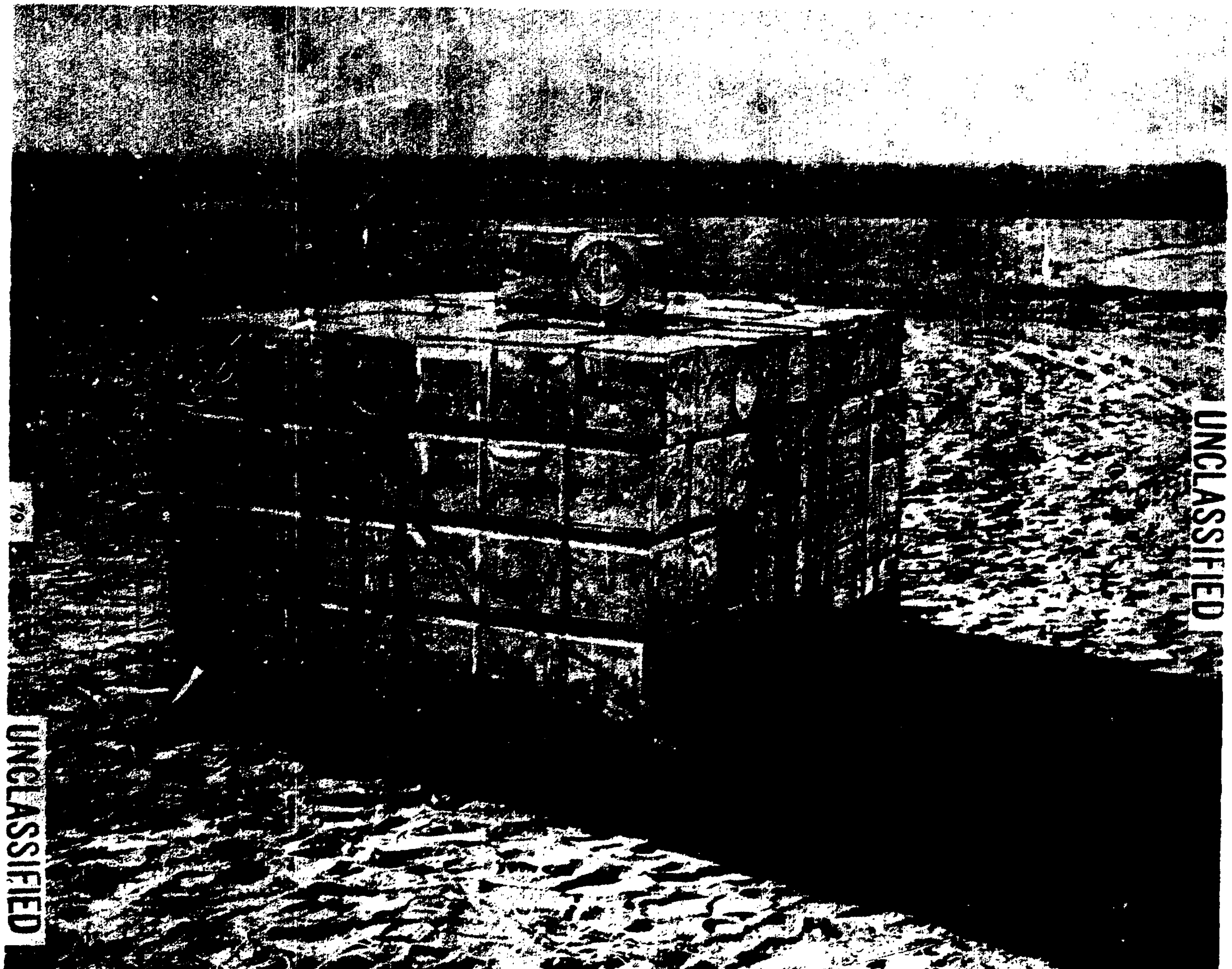

Figure 4

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Figure 5

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Figure 6

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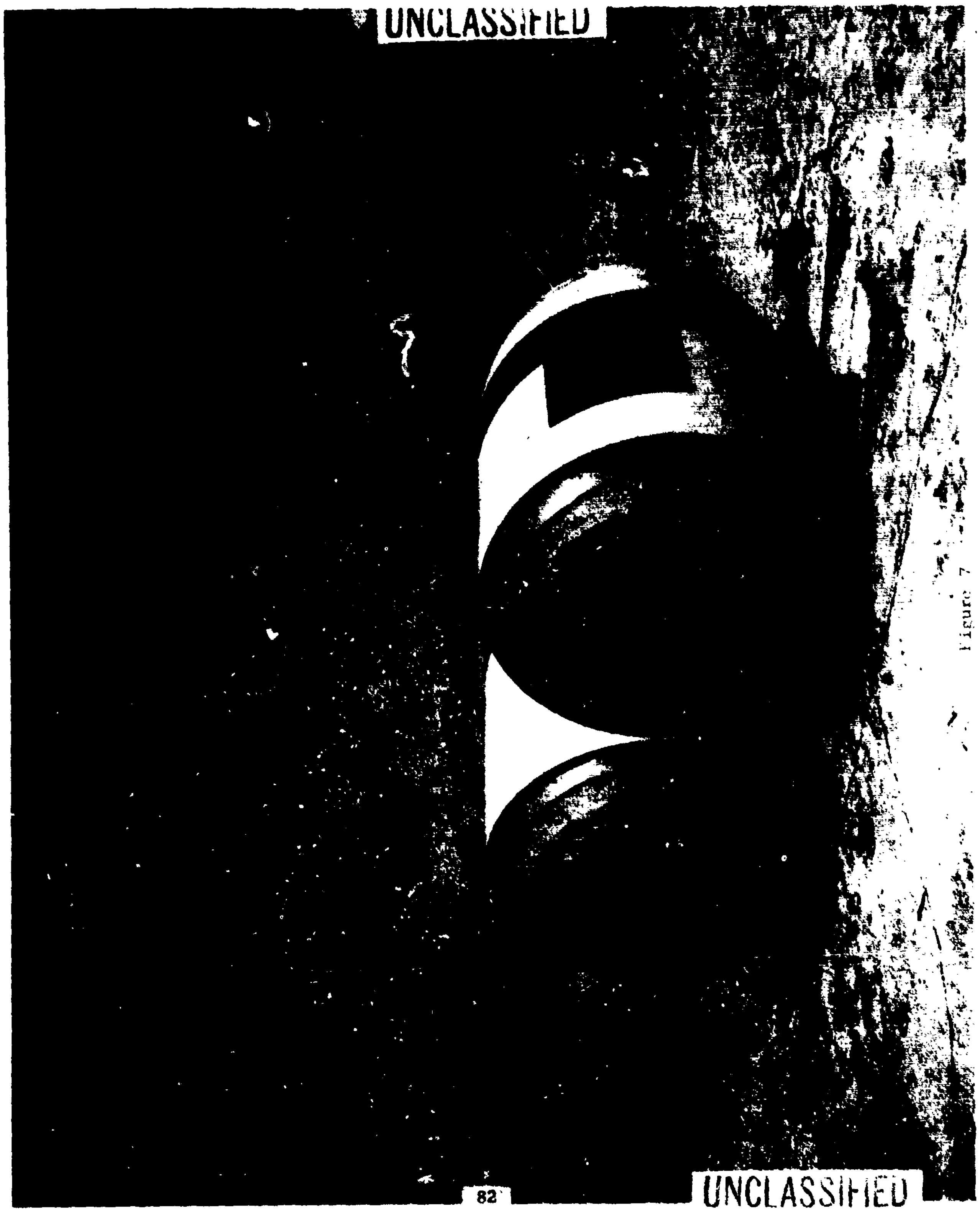

Figure 7

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Figure 8

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Figure 9

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Figure 10

Figure 11

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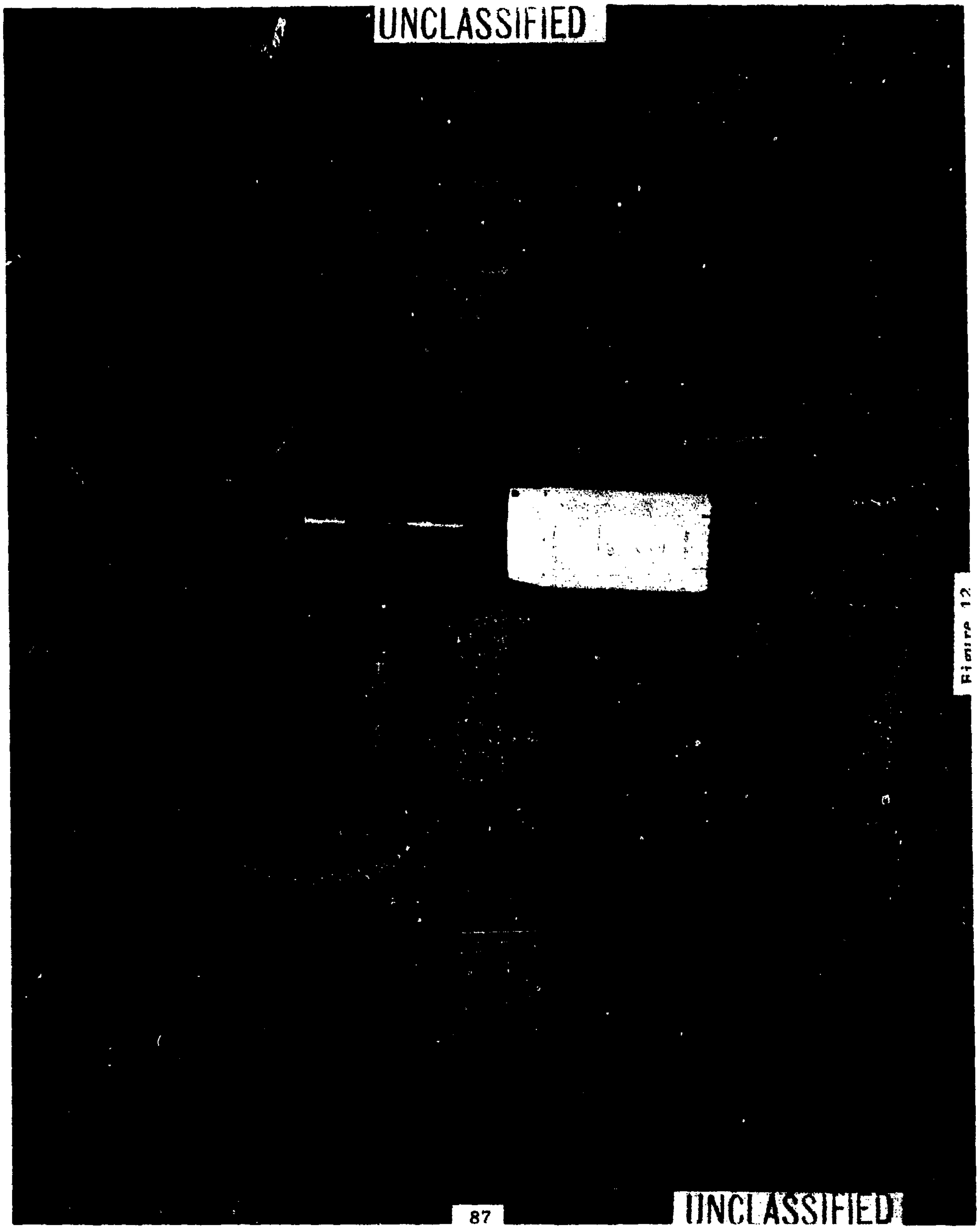

Figure 12

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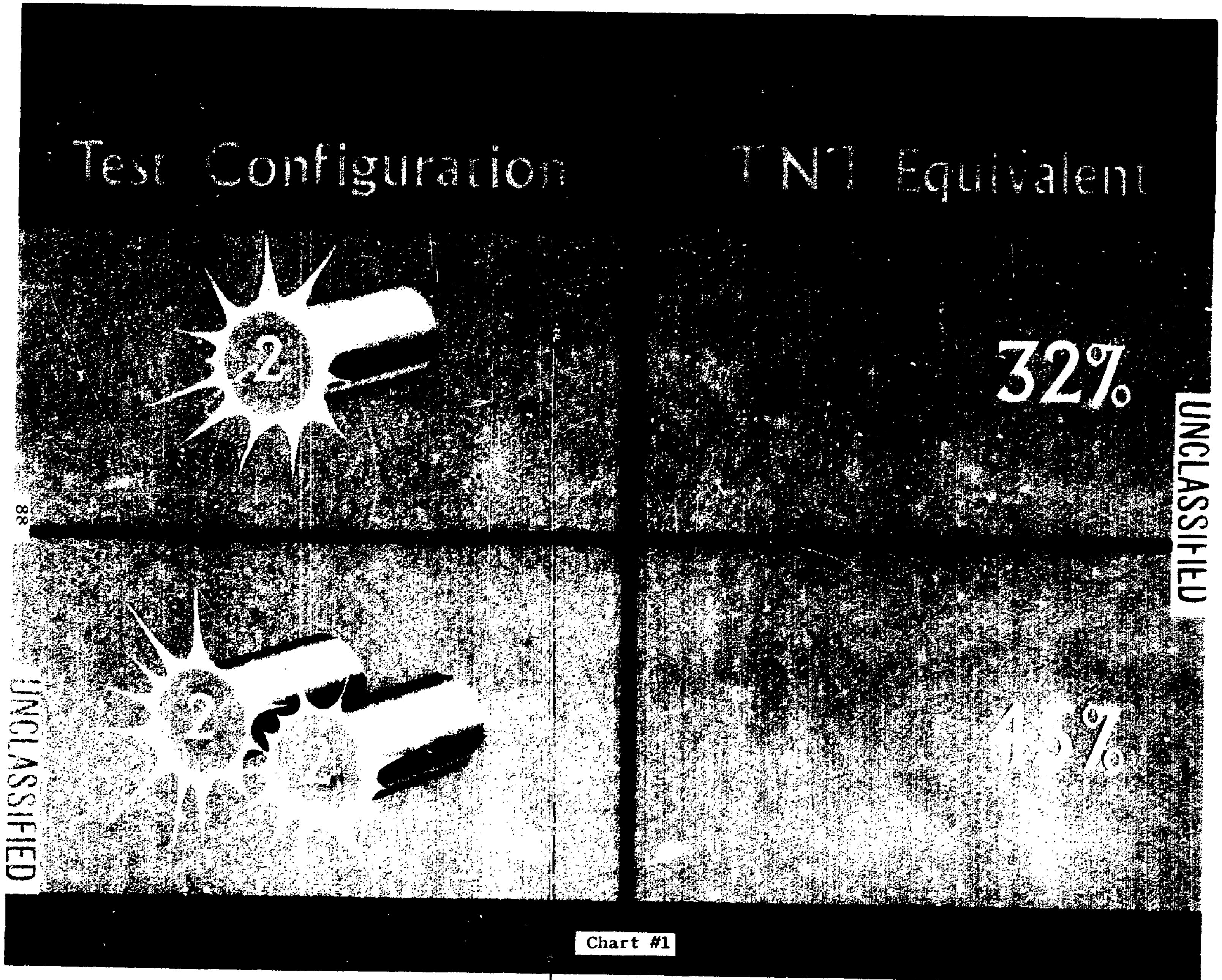
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Test Configuration
TNT Equivalent
2
32%
2
2
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Chart #1

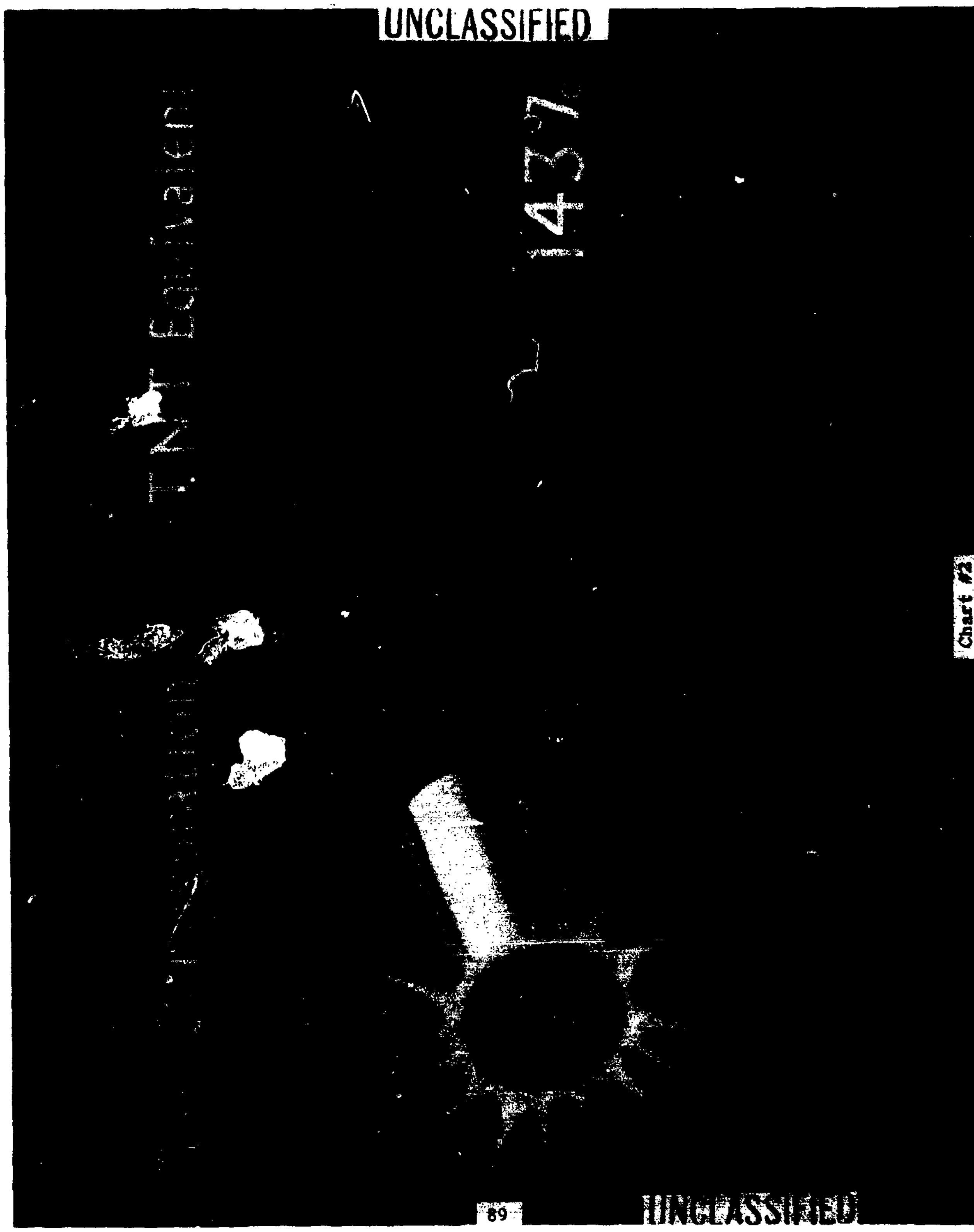

Chart #2

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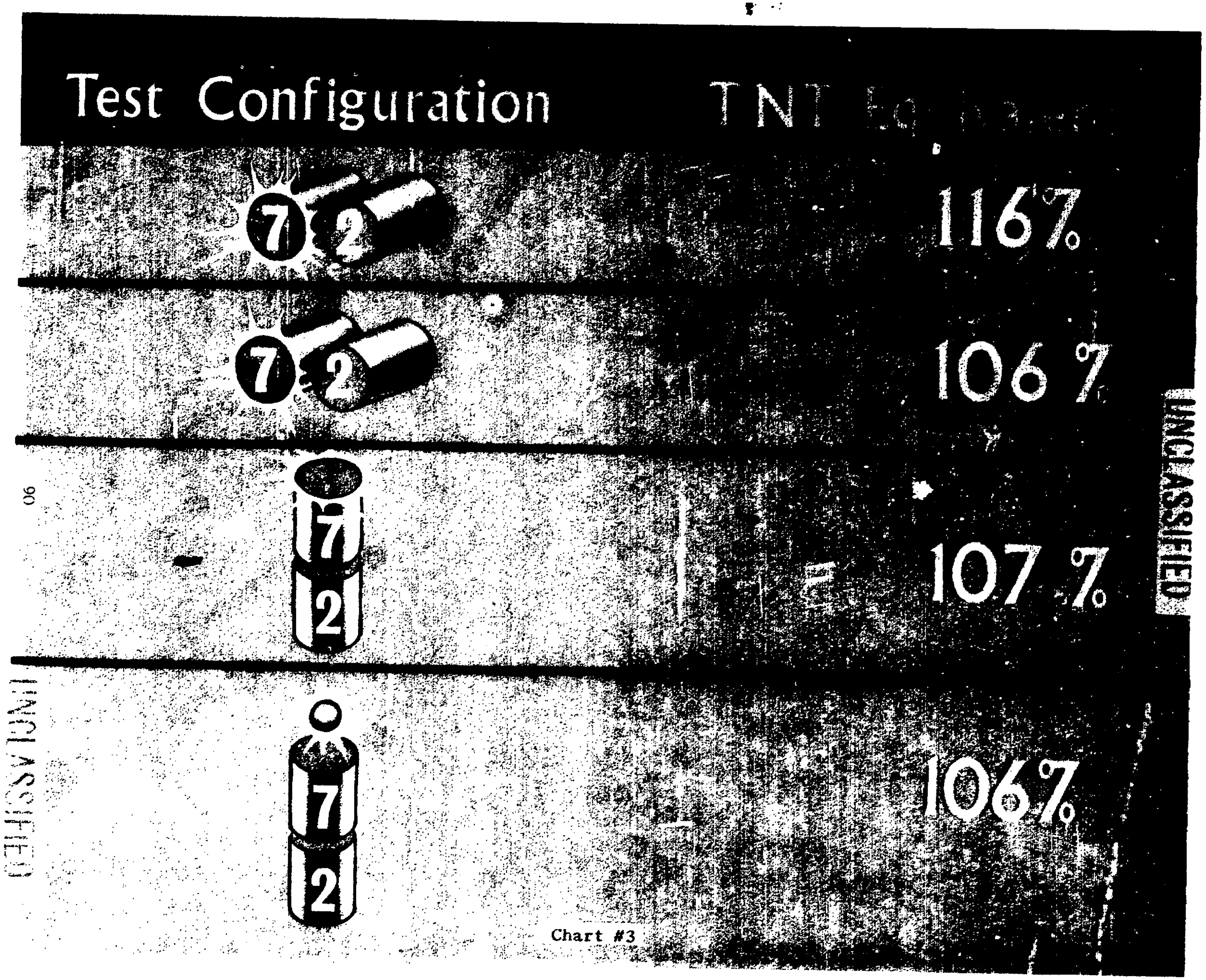

Chart #3

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Powers, Hq USAF: Do you intend to try any of the Class 2 materials or only Class 7 materials, or in combination?

Richey: You mean, when Class 7 and Class 2 is combined - no, so far our plans are when they are combined, to prime the Class 7 only.

Powers: Will you get a different result if you prime the Class 2 material when you're using it in combination with Class 7?

Richey: You mean use Class 2 as donor?

Powers: Yes.

Richey: And not prime the Class 7?

Powers: That's correct.

Richey: Undoubtedly you would get a very different result. We don't have this planned in the present series.

Powers: Usually I believe there is so much more of Class 2 material than there is of a Class 7 material in the combinations, the possibility of Class 2 material being fragmented or being detonated, let me say -

Richey: Acting as the donor?

Powers: Yes, by the donor, would be greater. Therefore, I would imagine that you would try to test this in combination by detonating the Class 2 material.

Richey: If we can secure enough surplus motors this is certainly an area that should be investigated obviously. I'm not sure, but I think we have sufficient Class 2 motors that we could look into this.

Powers: Maybe NASA will consider this.

Perkins: Just to elaborate slightly your question, what we are concerned with here is not the evaluation of a specific system. It is to get a base line to determine what we can get out of these propellants if certain types of incidents occur which could be foreseen in some types of installations. What you suggest is also a possibility but not necessarily the prime concern of this particular test series.

Price, NOL: Was your one control shot Composition B or cyclotol?

Richey: That was Comp. B.

Price: And you said it was a little bit above TNT, what was the TNT equivalent on that?

Richey: The TNT equivalency of the Comp. B charge?

Price: Yes.

Richey: It followed a typical TNT curve until you get in the closer distances. I don't remember now just what point it did cross, but in close the curve tends to become much steeper. One thing I neglected to point out, pictorially we only showed one calibration charge, Comp. B. In that same phase after we were thru, we did detonate the same amount of TNT. The TNT in our instrumented set-up gave us the same results.

Price: Close-in?

Richey: Close-in, again the yield from the TNT indicated that it deviated from the so-called standard curve, much sharper.

Price: Could you tell any difference on your curves, pressure-time particularly, or your class 2 materials as compared to the curves you get from comparable amounts of explosive?

Richey: They were a little longer duration which I would expect, its a little different yield.

Price: Different decay time?

Richey: The decay time is a little slower. You don't see the sharp peaks that you do in HE or Class 7. The Class 7 motors show a typical HE blast curve. The only way the Class 2 is different is that its a little slower in decay, the pressure is there, its just a little longer. We do have planned on this calibration in the next series, to detonate 5,000, 10,000, 15,000, maybe 20,000 pounds, several different calibration shots of TNT with a gage array as was outlined in the film. I have since added more instruments, I think in this film we only had six Kistlers. We now have ten in and we've increased the mechanical gages up to 26 that we're presently using. In essence we're gathering or measuring the overpressure four times at the same distance.

Roark, Aerojet-General: You indicated that your pressure-time history did not decay the same as TNT which I would anticipate - I would like to know where you chose on these records to make your TNT equivalency prediction, where you come out with things like 143% and 35% and some nice accurate-sounding figures like this. Did you take these in real close or out a long ways or in the middle or where?

Richey: This is an average, its quite a complicated system that we went thru in taking our overpressures, averaging them and then correcting them to a standard atmosphere; working them out to a scaled

factor and we actually went to a scaled chart then and worked up curves so that we made a direct transfer to come up with these pounds equivalency.

Roark: Could you give us any example of how this deviated from one end of the curve to the other end, say lambdas or R over W 1/3 of 3 or 4 out to maybe 20. Were they pretty much the same in terms of the TNT equivalents or did they deviate by a fair amount?

Richey: In close you get into a scale distance if I remember right on the curve. Its a scaled distance of about 5 1/2, where the TNT and Comp. B deviates from a standard curve and rises very sharply. I don't know whether this is really what you're asking or not.

Roark: No, I'm wondering where on this curve you pick to read this value to TNT equivalents -

Richey: You mean, did I go out and take the reading at 100 ft. or 500 ft.?

Roark: No, on this scaled distance I was wondering where did you make this estimate at?

Perkins: It was over a range of distances, averaged as he said.

Richey: From 80 ft. out to 2000 ft.

Roark: Ok, and what did this turn out to be in terms of lambda, typically?

Perkins: 5 to 50 W 1/3 or something of that nature.

Roark: Between 5 and 50, how much difference did you find the TNT equivalents between those two extremes, this is really what I'm trying to get at?

Perkins: I don't believe its been refined that much yet.

Richey: I haven't really looked at it that way.

Bishoff; AMC: My question is in the same area and I'm particularly interested in the peak overpressures at different distances from the point of the explosion. When you got the TNT equivalency of 143%, do I interpret that correctly when I say that at 100 ft., at 500 ft. that the peak overpressure is 143% of what it would be if it were TNT?

Perkins: It isn't figured exactly that way Fred, but the tests were designed to give an ability, based on the pressure readings, to determine high explosive yield over a range of distances and except for the anomalies which occurred in the very close-in region, not only

with the propellants, but with the calibration charges as well, which were TNT in one case and Comp. B in another. The high explosive equivalency of the propellant charges was reasonably uniform over the range of distances used. Does this answer your question?

Bishoff: I'm not sure yet. In choosing the site for a fixed missile system, what happens fairly close in to the missile is not of particular importance.

Perkins: Agreed.

Bishoff: What we're really interested in is what overpressures we will get at the end of our safety zones.

Perkins: I would like to emphasize again that the results that have been reported here are quite preliminary from an open end test program that is continuing and will be modified as the circumstances warrant based upon the results of each succeeding test. They do not yet have the indorsement of any of the producers of the material involved and they have not yet proceeded to the point where we at the Board Staff would even consider that we could use them as a basis for quantity-distance criteria and they are most specifically not for the purpose of evaluating the high explosive equivalency of any existing missile system. They are to provide a basis for evaluating the usefulness and verity of the term "high explosive yield" for solid propellants.

Bishoff: I just have one more statement on it. I find the 143% TNT equivalency for a Class 7 missile motor quite disturbing. If this is a true figure, we're in trouble, so if the figure cannot be substantiated I think we should be rather hesitant in using it at this time, at this point in our tests.

Perkins: Mr. Ullian has something to say on this subject. I think we must close this discussion with his comments.

Ullian, AFETR: Mine is not going to be argumentative at all. I just have a question on some of your future tests. I've heard all you've said about not trying to duplicate a particular system, but most of your tests seem to be a 1 to 1 ratio of 2 to 7. In other words, Class 2 propellant to Class 7, except for one possible future test that even it looks like its close to a 1 to 1 ratio. If you're going to try to finally come up with something that relates to most of the missile systems we use today and you look at the ratio of 7 to 2, it runs somewhere between 1 to 2, one being in the ratio of Class 7 propellant to maybe up to ten times that amount of Class 2 propellant. I'm wondering both from some of our experiences and some other work that's been done in the past, if you increase the ratio of Class 2 propellant. I wonder whether you aren't going to see, without arguing any way or the other on your percentages just using them as they stand,

a reduction in the contribution of the two to some degree. And I'm wondering if you plan in the future to try to come a little closer to the ratios in the missiles we're using today and will probably use in the future.

Richey: This is one of the things that we hope to find out using the Nike Zeus motor. I don't know whether you remember or not, I had graphically indicated that there were two in the end, vertical. This was end initiation then to investigate this very thing if I understand what you're saying to see if it does propagate.

Ullian: It still is going to be a 1 to 1 ratio, either by mass or by weight.

Perkins: Specifically, this program is designed to determine the effect of change in the ratio between the Class 2 and Class 7 components and to some degree, differences occasioned by different types of Class 2 components and by different velocities of detonation on the part of boost explosives. We have to proceed cautiously so that we don't get results which are not applicable to the problem but we hope that we will not have to quit before we get the answers to some of these kind of questions that are being raised.

Richey: And we do have in the back of our heads that as soon as we get the motors and facilities that we will make some of these tests under confined conditions to see what the relationship is between confined and unconfined.

Oberholzer: That was a very good presentation but I'm afraid the Range is going to kick us right out of Florida. I would like you to say a few words on whether you think the 120" solid motor tests conducted last year at NOTS which you couldn't get 10% yield out of was a valid and practical test for determining TNT equivalency.

Richey: I don't think there is any real similarity between the two tests. The stimuli was quite different. The 120" test was a dynamic impact, the motor was burning, there was no explosive as such - no HE on that motor, where the stimuli on this is the absolute worst. I don't know how else to answer your question.

Thru error in numbering, there are no pages 96 or 97.

ARMED SERVICES EXPLOSIVES SAFETY BOARD

SAFETY TEST PROGRAM

The first three years of the Armed Services Explosives Safety Board test program including destructive tests of cubicles, bays and steel arch igloos for evaluation of protection against propagation of explosions are summarized in a documentary report film BuWeps 9-64 entitled "Some Problems in the Storage of Explosive Ordnance." This film report is "For Official Use Only" and may be obtained by qualified requestors from the following sources:

Department of the Army

Army sponsored requestors should request the film by title from the appropriate Audio-Visual Support Center in the Army area in which located.

Department of the Navy

Commanding Officer
U. S. Naval Photographic Center
Naval Station, Anacostia
Attn: Film Distribution Dept.
Washington, D. C. 20390

Department of the Air Force

Commander
Air Force Film Library Center
8900 South Broadway
St. Louis, Mo. (Film Ref #SFP 1557)

National Aeronautics & Space Administration

National Aeronautics & Space Administration
Film Distribution Center & Library, Code AFEE-3
Washington, D. C. 20546

Requestors not sponsored by one of the four listed agencies should make request to the Naval Photographic Center. Requests should not be directed to the ASESB because this will necessitate their being forwarded to the appropriate issue center.

LOCATION AND TYPE CONSTRUCTION FOR PERSONNEL SHELTERS

L. C. Walther
Aerojet-General Corp.
Sacramento, California

A common sense approach to assessment of the location and type of construction used for control rooms and personnel safety shelters requires careful consideration of those environmental variations which, alone and in combination, pose a hazard to personnel.

The whole subject of personnel protection from explosive hazards is controversial, and many areas of uncertainty exist. For example, interpretation of projected yields and equivalencies of solid propellants is approximate, at best. The classification of propellants may be unnecessarily conservative, due to incomplete knowledge. Fortunately, effort is being expended in these areas and should contribute to the future establishment of realistic standards.

The basic objective of this paper is to (1) present a method of evaluating control room safety for personnel involved in such locations and (2) discuss potential hazards as related to propellant mixing operations.

The design of many batch mix stations in existence is an outgrowth of interpretations of explosive facilities construction as prescribed by Ordnance Safety Manual ORDM 7-224 prior to 1959 and supplemented by overpressure calculations of the Corps of Engineers Manual, "Fundamentals of Protective Design." The Armed Services Explosives Safety Board recommendations were utilized in quantity-distance placement of buildings and structures.

The above manuals did not specifically cover the location of control rooms required for remote operation and, in many cases, prudent engineering judgment was necessary in providing protective housing for operating personnel in the vicinity of this type operation.

A considerable amount of testing has been done in the last ten years, both with small nuclear and propellant charges rated by TNT equivalencies, and with actual TNT charges, in attempts to develop empirical information on pertinent characteristics of blasts. This mass of test data has been used to develop empirical relationships for such blast phenomena as peak pressure, shock wave propagation rate, particle velocities and duration of pressure pulses as functions of distance and explosive quantity.

The empirical relationships and test data now in existence have been applied by Aerojet to develop an approximate analytical tool for facility evaluation.

The method developed was used to evaluate the safety of several older mix station control rooms in the Aerojet complex. The results obtained pinpointed several potentially unsafe conditions. The conclusions of that study, combined with a concurrent structural analysis performed by the AETRON Division of Aerojet, contributed to a decision by Aerojet management to modify those facilities which need improvement.

The layout of a small motor mixing station which is typical of the facilities studied is shown in Figure 1. The basic blast wave characteristics of an assumed malfunction were obtained by assuming that the maximum rated batch for the facility of 2500 pounds of solid propellant detonated as a unit during a mixing cycle. The propellant was assumed to be equal to TNT, and the mixer was assumed to be the source of the detonation.

A number of well documented explosive malfunctions, which had occurred in the past, were examined to try to establish some equivalency standard. The malfunctions studied indicated that the propellant that detonates has an equivalency to TNT of approximately one. However, the portion of the batch which did, in fact, detonate varied considerably from case to case. It was decided that the most conservative approach was to assume that all of the propellant would detonate. This approach will always be either conservative or exact.

Consideration of attenuation has been limited to distance through which the generated shock wave travels. No attempt is made to allow any benefits for energy absorption in the demolition of the basic structure or for cratering activity or removal of barricade materials. Energy would be dissipated in this manner, but present information does not allow quantitative determination. Again, this approach allows for a conservative analysis.

The pressure field emanating from the detonation source is calculated in appropriate concentric intervals. At each distance, the factor

$$\& \lambda = Z/(W)^{1/3}$$

is calculated. With the λ factors, the peak overpressure of the primary wave is read from Figure 2. This curve was developed from test data by the Ballistic Research Laboratory, Aberdeen Proving Ground.

The velocity of propagation of the shock wave, and the resulting time of arrival of the shock wave at a point in the vicinity of the blast are functions of the peak overpressure. The induced particle or air velocity at the shock front is calculated by the relationship:

$$U_s = \frac{P_s}{1 + (P_s)^{1/2}}$$

where $P_s = p_s/p_o$ and $U_s = u_s/c_o$. This relationship was obtained from Reference (1). The velocity of propagation of the shock wave itself was calculated by the relationship Reference (1):

$$\dot{X} = \frac{3}{5} U_s + \sqrt{1 + (\frac{3}{5} \ U_s)^2}$$

in which $\dot{X} = \dot{x}/c_o$.

With this calculated shock velocity, the time of arrival of the primary blast wave at any point is obtained by averaging of the velocity over the distance increments and calculation of the elapsed time of travel of the wave for each increment.

Actual wave propagation characteristics, as applied to practical facility layouts, are seldom simple. There are usually revetments, indirect access roads and semi-enclosed areas, such as those in Figure 1. These non-ideal conditions produce reflections of the primary wave and secondary pressure fronts. The layout of Figure 1 will be used as an example in discussing these phenomena.

As the layout shows, the concrete pad in front of the control room is a semi-enclosed area. The shock wave, as it moves across the space over the control room entrance, generates a secondary wave which travels down through the semi-enclosed volume. The secondary wave reflects off the concrete pad and, with very little attenuation, moves back up into the air space over the control room entry area.

The assumption was made that the semi-enclosed volume in front of the control room entrance acted as a tunnel. The appropriate charts for secondary shock waves and reflected shock waves in Reference (2) were used to obtain pressures over the face of the entrance. Positive pulse durations were calculated by the relationship:

$$\log T^{+}_{p} = 2.7995 + (1/3) \log W - 0.2957 \log p_s$$
$$0.0376 \log p_o - \log c_o$$

This equation was obtained from Reference (1). The two pulses, secondary incident and reflected, were handled separately, with travel times of these waves to the ground, then back up, taken into account. In the case of the reflected wave, the values of ambient pressure (p_o) and sound velocity (c_o) used were the induced total pressure and resultant higher sound velocity created by the passage of the incident

wave. The pressure-time curves obtained in the calculation described above are shown in Figure 3. The final portion of the curve will be discussed later.

As shown in Figure 1, two reflections from revetments were considered. Reflected pressure from an obstacle is a function of several factors, including the incident pressure, the size of the obstacle in relation to its distance from the incident pressure source, and the angle of the obstacle, with respect to the propagation vector of the incident wave. Thus, a spherical shock wave striking a plane wall large enough for the curvature of the wave front to be important will generate a spherical reflected wave. A reflected wave of this type can have a secondary effect at considerable distances from the initiating obstacle, to the extent that pressures in a region acted on by both incident and reflected waves while they are still of considerable strength will experience overpressures which are multiples of what one would expect from the effects of the incident wave alone. Duration of the overpressure pulses also enters into this effect, as does the phase relationship of the two shocks in that region. Thus, the determination of pressure-time characteristics in a region such as the barricaded area around the mix station is not simple, and some simplifying assumptions are necessary.

The nearest revetment was examined first. The revetment is only 20 feet from the blast source, on a line drawn such that the incident shock, and a reflection which would pass over the same point above the control room as the original shock front, are at equal angles to the revetment. The reflected shock equation of Reference (3) for air was used, with a reduction by the cosine of the angle of incidence.

$$p_r = 2p_s \frac{(7\ p_o + 4\ p_s)}{(7\ p_o + p_s)} \cos \alpha$$

The calculated overpressure, if assumed to emanate from a mirror image source located behind the revetment, gives unrealistically high pressures at a distance, and implies the assumption, working back through the quantity-distance-overpressure chart (Figure 2) of a source explosive yield greater than the true quantity. Accordingly, the reflected wave is assumed to emanate from a source whose distance from the revetment is determined by the original explosive yield. This assumption gives a more reasonable pressure decay with distance. The velocity and arrival time of the reflected shock are calculated in the same manner as the original shock, the travel times of incident and reflected shocks being summed to obtain arrival times after the time of burst.

The second reflected shock, which is a reflection of the initial shock off the revetment opposite the control room, is treated somewhat differently. The strength of a shock reflection is a function of the cross section of the obstacle in relation to the relief volumes around

it. In the case of the second reflection, the wall is 15 feet high, compared with a hemispherical shock radius at that distance of 65 feet, and has an open area directly above it which is unlimited. In addition, the revetment is at a 36° angle to the path of the incident shock wave, which is to some extent obstructed by the earth revetment and a sloping concrete wing wall surrounding the control room. In cases like this, the shock is assumed to reflect at the same strength as the incident wave.

The final arrival time of both reflected waves was .0238 seconds. The overpressure levels of the first and second reflections were 29 psig and 26 psig, respectively. However, as shown in Figure 3, the primary pressure level in the entrance region at .0238 seconds is approximately 38 psig. As a result, these reflected waves would not actually enter the entrance region as shocks, but would be deflected away, resulting in a minor compression wave in the entrance area which would slow the rate of pressure decay and extend the duration of the positive pressure pulse. This effect is most easily dealt with by fairing the curve on an educated guess based on doubled back pressure and resultant doubled remaining duration. The change is shown in Figure 3 as a point change in slope of the pressure-time curve.

The identical arrival times, and almost identical pressure levels, of the two reflections considered, are to some extent a justification of the assumptions made in the analysis. The actual pressure-time contours for the region surrounding the mix building would be affected by a multitude of minor reflections and interactions of the original shock wave, and would not show sharp discontinuities from one region to another or from one time to another, but would actually be continuous, if heavily sloped, variations. The nearly identical results, for one location, of the independent calculation of two shock characteristics is thus in accordance with the expected result.

The work discussed to this point is actually preparatory to the real items of interest, namely the overpressures and dynamic pressures experienced inside the control room. The overpressure curve shown in Figure 4 was calculated according to an interative procedure defined in Reference (2). The assumptions made were that the panel door to the control room held long enough to prevent shock wave generation and reflection as such in the entry corridor. The control room and entry were considered to be one chamber for volume calculations, with reductions being made for equipment housed in the control room.

The interative process involves the relationship

$$\Delta P_c = C \frac{A}{V} \Delta t$$

in which C is a constant, read from a curve in Reference (2) and having the dimension ft x psi/sec., which is plotted versus the pressure differential across the chamber entry.

Figure 5 shows the induced velocity and displacement of a 165-pound man standing in the entry corridor of the control room, facing either towards or away from the door. This curve was generated by an interative process similar to that used for the chamber overpressure calculation. The force applied to a standing man is basically a function of the dynamic pressure applied by the induced wind velocity. The drag characteristics of the human body were drawn from Reference (4), which lists for a man in the position defined a frontal area of 5 square feet and a drag coefficient of 1.0. These values were applied to the equation:

$$F = C_d \, qA = m \frac{dv}{dt}$$

The man was assumed to have no initial velocity, and the calculation applies to the man's center of gravity and does not take into account the effects of tumbling. Since dynamic pressure, "q", equals the total pressure minus the static pressure, and these are known from previous calculations, dynamic pressure was not separately calculated, but was replaced by the differential pressure values.

The hazard to personnel due to a chemical detonation falls into five categories: (1) direct biological effects of induced overpressure, such as burst ear drums, lung damage, internal pressure hemorrhage, etc; (2) external injury due to collapse of structures on personnel; (3) external injuries, cuts, contusions caused by flying debris; and (4) injuries (broken bones, skull fracture, concussion) due to physical displacement of personnel by the blast-induced wind velocity; (5) thermal effects, producing burns. The work reported here involves personnel hazards due to a detonation occurring in the course of normal propellant mixing operations, which implies that all affected personnel are either at their stations or outside the area in which the detonation occurs. The inhabited areas of mixing stations should be designed to withstand the direct shock effects of a detonation at the rated quantity limits of the station without sustaining major damage. Thermal effects of a chemical detonation of 2500 pounds of propellant during mixing, for example, are such that only persons inside the mix station area who were directly exposed to the blast would be burned. As no one is supposed to be in such a location, thermal effects are not considered.

Two types of personnel hazard are associated with overpressure; ear drum rupture and lung damage. According to latest studies, Ref. (5), the threshold for rupture of the human ear drum is 5 psig, or 2.5 psig reflecting to 5 psig (near walls and other shock reflective surfaces). The threshold for hemorrhage in the lung tissue, and associated damage such as bruising of the heart, is 15 psig, or 6 psig reflecting to 15 psig. More recent information indicates that the lung damage criteria will be lowered to 10 psig or 4.5 psig reflecting to 10 psig.

Obviously, the value and depth of this subject does not permit time to discuss all aspects in detail. However, here are a few safety factors which should be considered in the design or siting of a facility.

1. Care should be exercised in the use of so-called safety shelters or escape ramps. An incorrect evaluation of the tunnel effects due to overpressurization could make these a death trap.

2. Insure that any cryogenics, tanks for cleaning solvents or other equipment are located outside the immediate area or are buried underground. Similarly, piping and electrical lines in exposed areas should be buried. Rupture or displacement of such equipment by the blast wave can cause fires or generate widespread area hazards.

3. All openings (doors, vents, air conditioning) into inhabited structures should be designed to withstand calculated overpressures. Ducting should be indirect, with blowers mounted in a passage with a blind trap end, to catch any fragments of fan and prevent them from entering the control room. Total vent area to the control room, including door vents and ventilation passages, should be sized such that induced overpressure inside the building is kept within acceptable levels.

4. Floors inside inhabited buildings should be covered with a shock absorbent material to relieve ground shock and provide an additional biological safety factor for control room personnel.

During hazardous operations, inhabited building entrances should be kept closed at all times.

Personnel must be warned against storage of miscellaneous unauthorized items in the control rooms, and inspection to insure compliance with this rule must be frequent and regular. This requirement assumes prior careful provisions for the authorization of equipment necessary for the comfort and convenience of the working staff, and the proper choice and installation of such equipment. Safety helmets should be provided for all personnel working in the line areas, and the wearing of them at all times when in exposed areas, or while performing mixing operations, should be mandatory. The overwhelming majority of serious accidents caused by detonations are head injuries.

In brief, accompany sound analysis and design with proper safety procedures, and give your safety personnel the authority to enforce them.

The approach to facility evaluation utilized by Aerojet can be used to provide a valid evaluation of an existing facility. We have attempted to incorporate the knowledge which has been acquired over the past ten years regarding blast hazards associated with detonations of propellants with a sound analysis of associated biological effects.

This approach, coupled with additional studies in progress, is a first step towards development of realistic standards and facility design criteria.

Remember, safety is not merely a matter of complying with certain requirements, but insuring that adequate personnel protection is provided.

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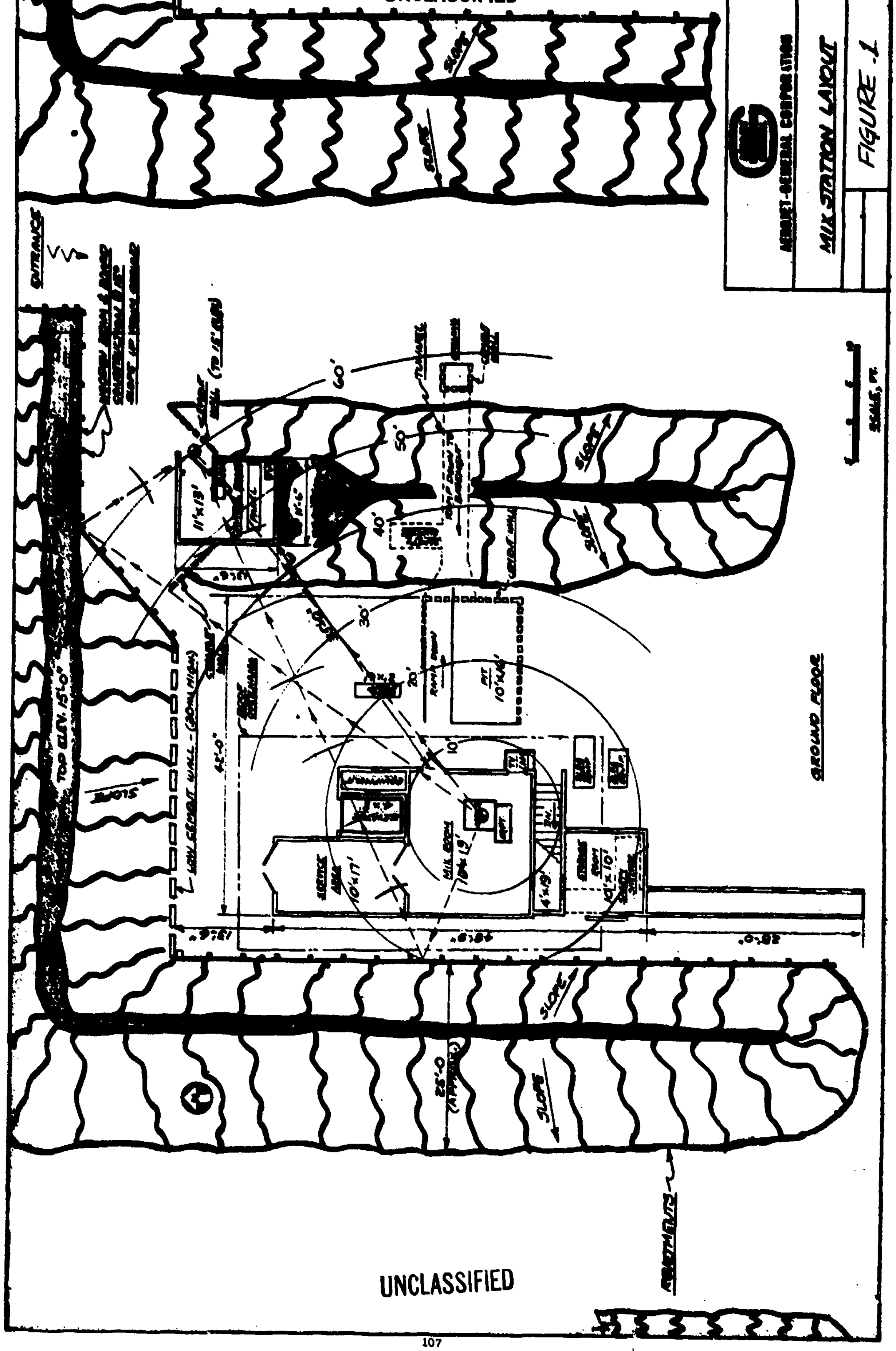

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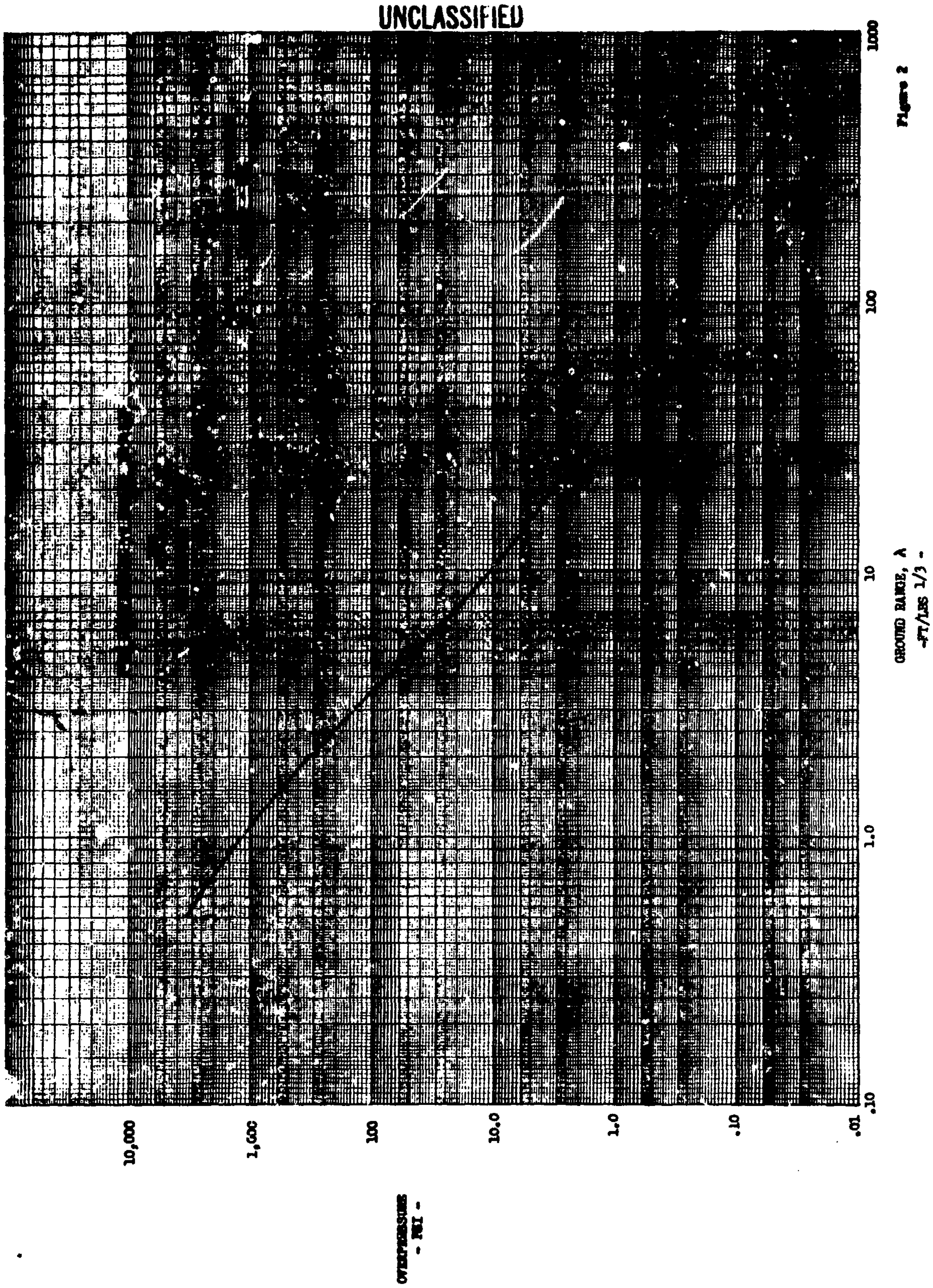

1000
100
10
1.0
.10
GROUND RANGE, λ
-FT/LBS 1/3 -
10,000
1,000
100
10.0
1.0
.10
.01
OVERPRESSURE
- PSI -

Figure 2

OVERPRESSURE vs TIME AT CONTROL ROOM ENTRANCE

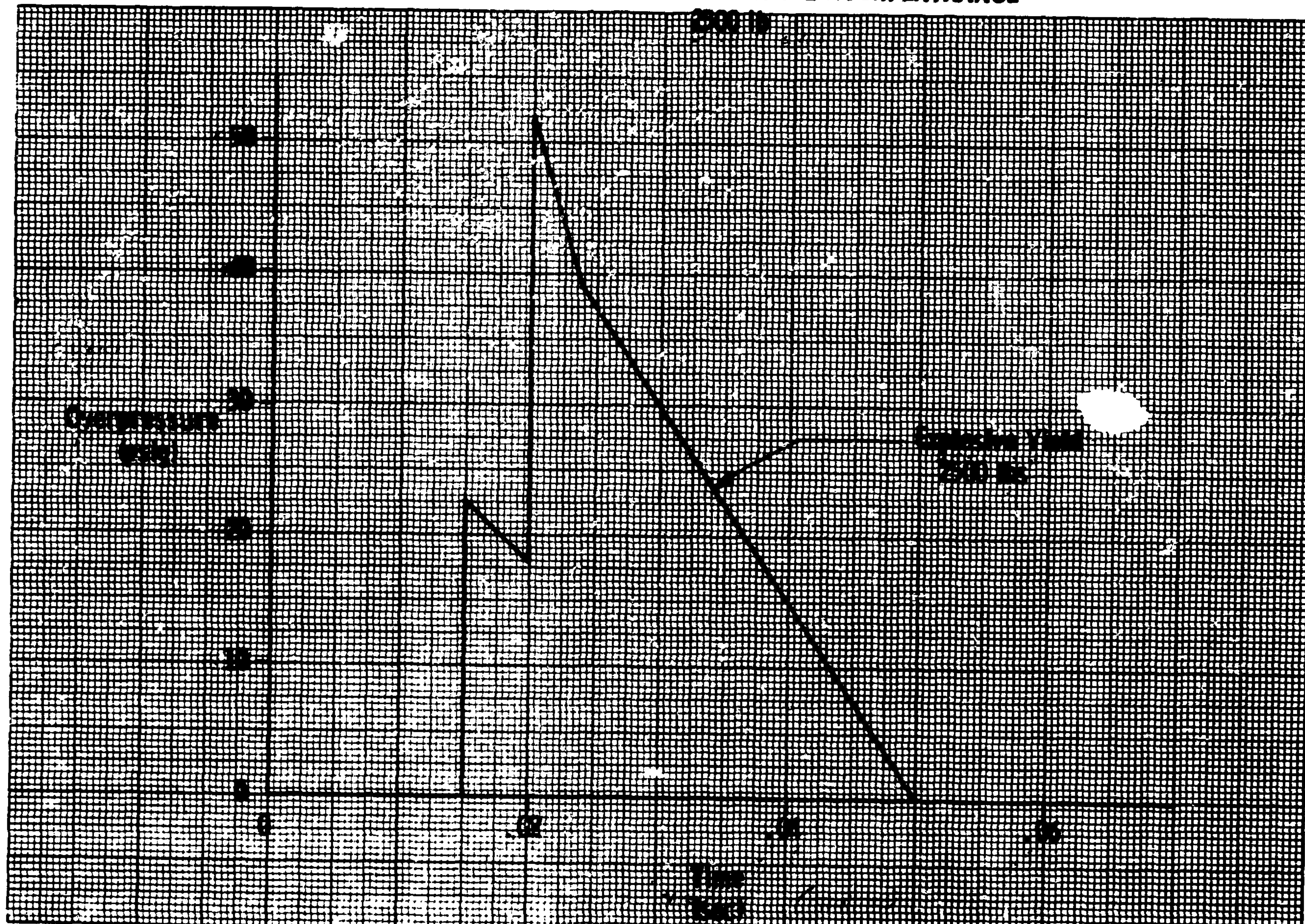

Figure 3

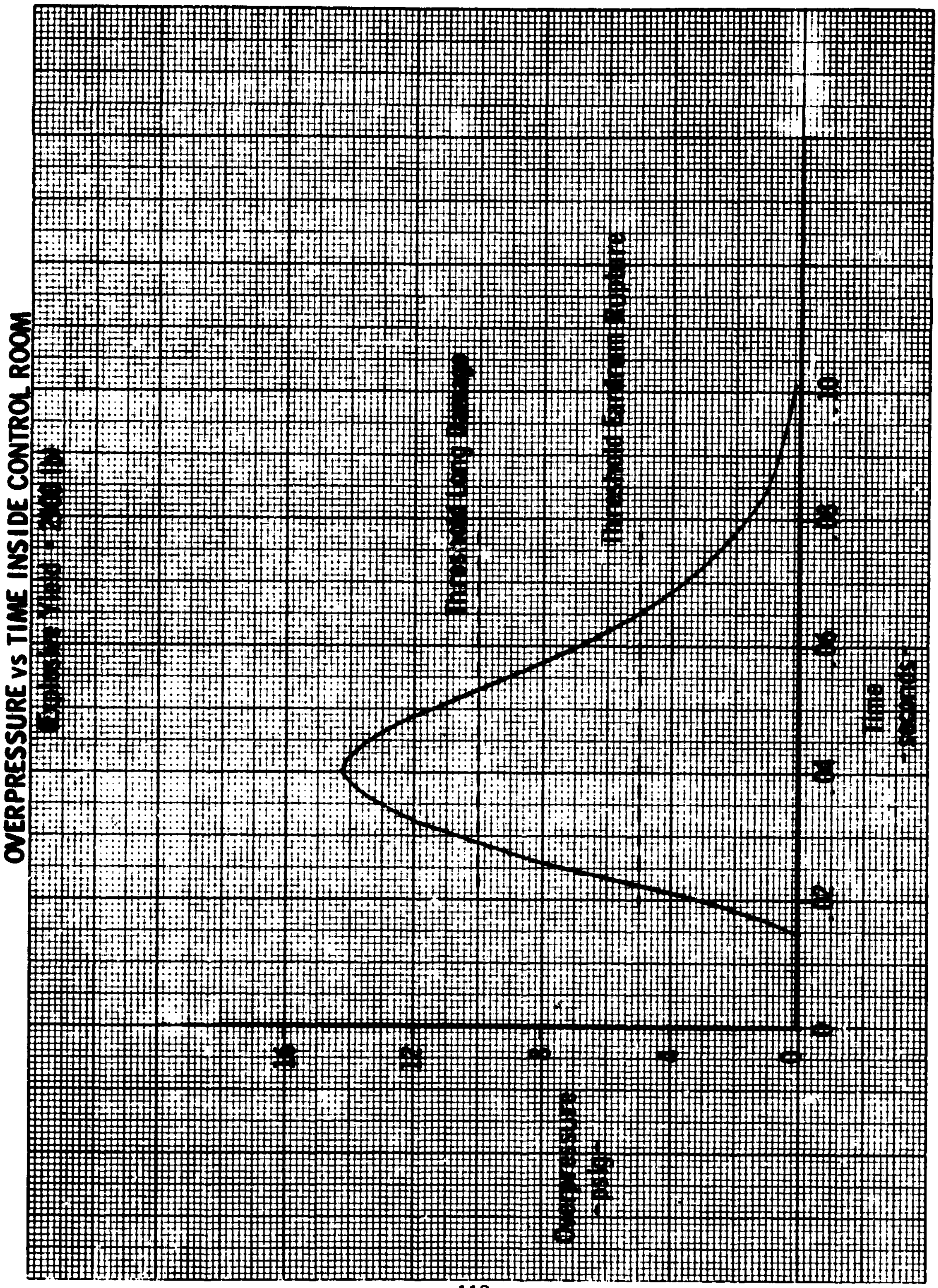
OVERPRESSURE vs TIME INSIDE CONTROL ROOM
Threshold Lung Damage
Threshold Eardrum Rupture
Overpressure
- psig
16
12
8
4
0
0
.02
.04
.06
.08
.10
Time
- seconds

Figure 4

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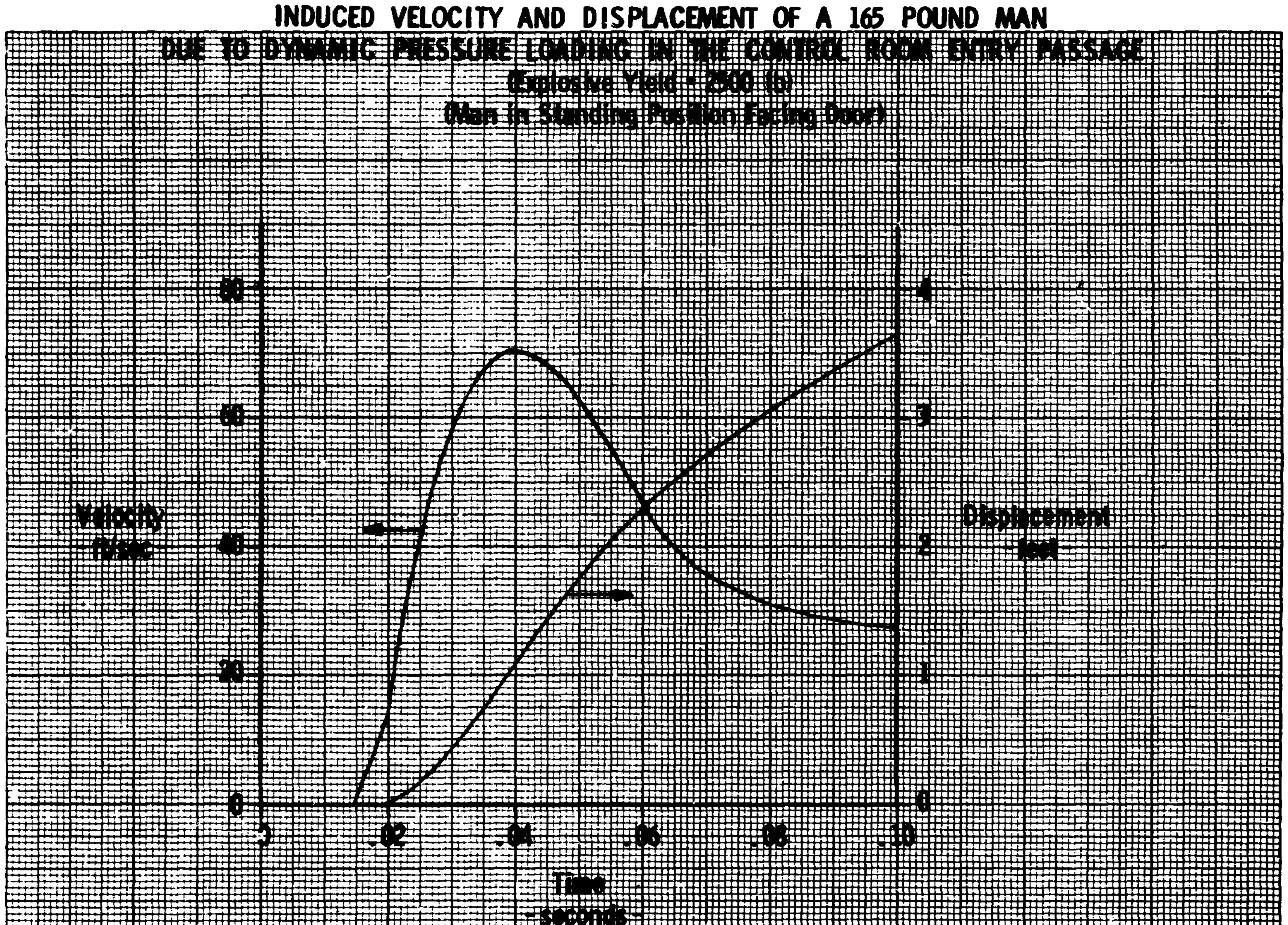

Figure 5

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NOMENCLATURE

<u>Symbols</u>

A	Cross section area	ft^2
C_d	Drag coefficient	-
c	Velocity of sound	ft/sec
F	Drag or displacement force	lb_f
m	Mass	lb_m
P	Pressure ratio to ambient	-
p	Pressure	lb/in^2
q	Dynamic Pressure	lb/ft^2
t	Time after detonation	seconds
t_p^+	Duration of positive pressure pulse	seconds
U	Air velocity ratio u/c_o	-
u	Blast-induced air velocity	ft/sec
V	Chamber volume	ft^3
v	Blast-induced velocity of personnel, equipment or fragments	ft/sec
W	Explosive yield (in terms of TNT as a standard)	lb
$\dot{X}$	Shock velocity ratio $\dot{X}/c_o$	-
$\dot{x}$	Velocity of shock wave	ft/sec
Z	Distance from blast source	ft
α	Angle between plane obstacle and shock wave front	deg
λ	Quantity-distance factor	$ft/(lb)^{1/3}$

SUBSCRIPTS

c	Condition in control room
o	Ambient or undisturbed condition
r	Reflection condition
s	Condition at shock front

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THE SKID TEST:

OBLIQUE IMPACT SENSITIVITY OF EXPLOSIVES*

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To the variety of sensitivity tests for high explosives and for propellants, most of which have been in use at many installations for some time, we can perhaps add a relatively new one having some unique features. It has the nickname of the Skid Test, and it is a test of oblique impact sensitivity of large, solid, bare HE charges. Traditionally, sensitivity tests are done on very small quantities, and give numbers which have highly apparatus-dependent meaning, or tend to rank the materials in orders of sensitivity; in a few cases, they have some real physical or chemical meaning. As I hope to show, the valuable output of this test is a sensitivity number which is directly relatable to operations such as manufacturing or handling.

The test had its beginning in an investigation to uncover the cause of an accident which occurred while a large, bare (uncased) HE charge was being transported by forklift truck in a box. The forklift suddenly stopped, spilling the piece which detonated upon impact with the concrete floor. The elevation from which the charge dropped was lower than that thought to have been dangerous. The investigators attempted to reconstruct the incident by swinging a charge, like a pendulum, to impact a floor at an angle; they found that this was indeed a good mockup of the accident, and that the heights from which reaction could be made to take place on many common explosives was considerably lower than would have been forecast from other laboratory tests or from an analysis of the amounts of energy involved (only a few calories). All this occurred in early 1961. We began the test about the middle of 1961, first developing instrumentation and techniques for actually doing the test, then examining some of the parameters of interest in such tests, and now using it as an everyday means of sorting out explosives as to sensitivity and to examining the safing or desensitizing effects of floor coverings and such uses. The Los Alamos Scientific Laboratory also does the skid test, principally in a vertical drop version onto a slanted target pad.

A movie which will be shown a bit later will describe the general configuration better than I can, so I will start instead with the description of the materials that are used. The test material is normally a 25 or 50-pound hemisphere of high explosive. With ordinary

*Work performed under the auspices of the U.S. Atomic Energy Commission
**Contractors to U.S. Atomic Energy Commission

explosives at their usual cast or pressed densities, this is a hemisphere of 5-1/2 or 7-inch radius. Sometimes we have used a 5-1/2-inch by 5-1/2-inch cylinder of explosive having a 5-1/2-inch spherical radius on the bottom, filling out the rest of the hemisphere with a plaster loaded with iron oxide to match the density of the HE. This is to conserve explosive when it is new or scarce. In general, it reacts about the same as the solid HE hemisphere, providing the height of the cylinder is the normal full thickness of the hemisphere, but is somewhat troublesome to make and use. The other basic materials comprise the gritty target. The target is made to resemble concrete but, of course, has been standardized for the usual laboratory reasons. Briefly, it consists of graded white silica sand bonded with an electrically conducted epoxy to a steel plate (about 16" x 16" x 1/4"), which is in turn glued to a large, thick concrete pad (30" x 30" x 8"). The sand is made electrically conductive by chemically depositing a very thin coating of silver for timing reasons described below.

Facilities necessary to such a test are similar to those in many HE diagnostics laboratories. One needs a drop tower or pendulum pole and appropriate tackle; an HE firing and observation building or area are required, along with equipment such as sequence timers, oscilloscopes, high-speed cameras, blast gages, etc.

Let us anticipate the movie a bit, and describe some of the geometry of the event. The hemisphere is loosely supported in a wooden ring, so that upon impact the ring can drop free while the hemisphere interplays freely with the target surface. The assembly is lifted and supported by cables attached to the ring at the bottom and a drop pole arm at the top, so that the equator of the hemisphere remains parallel to the ground in dropping. We usually use two cables in the plane of fall; but for increased lateral stability we sometimes use three. The hemisphere in its ring is lifted remotely by a winch. The safing blanket over the pad and a thermal blanket (used to keep the HE surface at a constant temperature because some explosives are too responsive to temperature in their changes in physical properties) are removed automatically. The sequence timer starts cameras, triggers oscilloscopes and actuates a solenoid, allowing the assembly to swing onto the gritty pad at a variety of angles, described later.

The data obtained are kind of reaction (in the high-speed films), time from contact to light or shock, blast pressure, and visual evidence regarding damage or crater, amount of HE left, etc. The principal data is that in the high-speed films because therein one can determine what kind of reaction occurred. The time from first contact is measured by means of fine wire (0.004" in diameter) stretched over the pole of the hemisphere and contacting the silvered sand mentioned earlier. This gives "time-zero" accurate to within a few microseconds, and the time to reaction is then taken from photodiodes if light is produced, or from shock arrival at piezoelectric transducers attached to the

underside of the steel, or derived from the high-speed films by means of a fiducial light which is fired by the circuit which closes at t-zero (that is, the first touch of the wire to the silvered sand triggers a capacitor discharge unit which fires a flash bulb, which is in the field of view of the cameras; the number of frames from then until a reaction, if any, are then counted; knowing the framing rate by means of timing markers, one can determine the length of time it took the event to occur, $\pm$ 1 frame). Blast pressure is measured by BRL gages or derived from shock velocity which is measured by short-circuitry timing switches.

The reactions obtained in this test are mild, moderate, or violent. The mildest is #1, which is only a scorch mark on the target pad or on the HE charge, with no other visible or recorded evidence (characteristic odor is sometimes detected). The other mild reaction, #2, is a puff of smoke clearly visible in the films, but yielding no light and no blast pressure, and usually not breaking the HE. Moderate reactions we call #3 and #4. These produce light and consume a small to moderate portion of the HE, but there is clearly a fair amount of the explosive unconsumed. Pressures are typically in the tenths of psi at 40 feet. Reactions #5 and #6 are violent; #5 consumes essentially all the HE, produces a lot of light and several psi; #6 is detonation, with all its normal consequences. The blast pressures are, in general, used simply to verify the levels of reaction.

With respect to the length of time it takes the event to occur, we have observed essentially no reactions at much less than a half of milli-second nor much longer than 1-1/2 milliseconds except in rare and unusual events (for example, in double bounces). There have been one or two instances of reactions just under a half millisecond.

Early in the development of the test, we decided to investigate the effect of impacting at different angles. Since it was clear that sensitivity at 45° was considerably greater than it was at 90° or vertical impact, the thought came to mind that at still lower angles sensitivity might be even higher; thus we undertook to investigate 26°, 14°, and 7°, as well as higher angles including 63° and 76°. These angles were chosen to have integral ratios of horizontal to vertical instantaneous (at impact) force vectors. In the order described, these are 2:1, 4:1, and 8:1 horizontal to vertical at the angles below 45°; 1:2 and 1:4 at angles above 45°. It was found that reaction was greatest at the 14° angle, decreasing in sensitivity at 7°, 26°, and above 45°. By sensitivity in this case, I mean the height at which reaction occurred. The kind of reaction does not seem to be a function at all of the impact angle. Thus as one approaches grazing incidence, which would resemble most of the old friction tests, sensitivity goes down, and this possibly explains why the standard frictional tests often fail to give any results on most of today's modern bulk explosives. The angle effect was investigated on a few explosives, although not all by any means,

with the same results. We have now standardized the test at 14° and 45° from horizontal.

Another subject for investigation was the size and charge geometry effect. In this investigation, we obtained essentially the same reactions in the 50 and 25-pound hemispheres, although on occasion no detonation occurred in the 25-pound hemisphere, probably due to the deflagration-to-detonation transition not occurring in the shorter 5-1/2-inch travel. It is quite possible that small height-sensitivity differences could be observed if one investigated closely, because as the charge gets much smaller then the effect of size on minimum reactive height does begin to show up. The 50 and 25-pound hemispheres, of course, have different impact surface radii--7 inches versus 5-1/2 inches--but the effect of changing radius without changing weight could not be clearly determined. In other words, it is possible that the 25-pound hemisphere, though smaller, reacts height-wise like a 50-pound hemisphere because the lesser weight is compensated for by a sharper radius. We do not know whether this is so or not yet, and I doubt that we will since we are not actively investigating it.

The trick of putting an HE cylinder in plaster to save HE, as mentioned before, appears to be valid in that it gives essentially the same reactions as the solid piece if the surrounding plaster is such that the entire assembly is as strong as a solid hemisphere would be. It turns out that to do this is often more expensive than making the whole thing out of explosive in the first place, and so we do not usually do it unless we are forced to for other reasons.

To mention a few actual results, one plastic-bonded pressed explosive, rich in HMX (approximately 95% HMX in a plasticized nitrocellulose binder), detonates when dropped from a height of 5 feet to impact at 45°. It will also detonate when dropped from a height of 1.75 feet when impacting at an angle of 14° from the horizontal. Below these heights, there are no reactions. Another plastic-bonded pressed explosive, rich in RDX (approximately 90% bonded by a chlorinated fluorocarbon), will detonate in drop from 3.5 feet impacting at 45°, or 1.25 feet at 14°. Again--as in virtually all cases--there are no lesser reactions below the height at which the characteristic reaction occurs. A third HMX-rich PBX (approximately 85% in a fluorocarbon binder) gives only mild reaction--on rare occasions #3--from 7 feet at 45°, and from 2.5 feet at 14°. But another HMX-rich PBX (90% in a resilient polyurethane rubber) gives no reactions at either angle up to 20 feet. Thus, it can be seen that there are differences clearly established in sensitivity, and the test is able to differentiate various formulations and kinds of basic explosives, in terms of both the height at which they will react and the kinds of reactions involved.

Having established that there are differences in sensitivity among explosives and explosive formulations, and having established to some

extent the effect of the variables of the test itself, it remained to discover what variables in the HE itself would yield changes in reactivity or height-sensitivity. It turns out pretty much as one intuitively thinks it should, with respect to the effects of composition, strength, and particle size, for example. As you might suspect, greater percentages of HMX in a particular formulation leads to more violent reaction, as well as more height-sensitivity. The particle size effect--that is, the tiny particles of HMX, RDX, or whatever the kind of explosive might be, and not the flakes, pellets or granules of castables before melting or PBX's before pressing--is noted principally as increases in reaction level with larger particles. There is, however, a strong interdependency with composition, and most particularly with strength. In fact, strength is one of the most important variables in setting the sensitivity. The stronger or more rigid the explosive is (physical strength, such as compressive or tensile strength), the more height sensitive it is. The kind of binder used is also closely related in some manner to strength, and is very effective in changing the sensitivity also. Soft binders or those that melt--for example, polyurethane rubbers or TNT--yield lower sensitivity formulations than those which are brittle, rigid or hard.

There is one other kind of desensitization which can be done other than making the HE less sensitive and that is to desensitize the impact surface, which of course is, at high probability, the floor. It has turned out that almost any kind of soft flooring material, such as battleship linoleum, rubber sheeting, vinyl linoleums, etc. will desensitize almost completely from any heights likely to be encountered in operations with uncased explosives. The one possible exception is an asbestos-filled vinyl, which produced reaction (detonation) from about 7 feet with an explosive which normally detonates at 1.25 feet. Since it is quite unlikely one would have in normal handling operations opportunity for a drop of more than 7 feet, this material too, therefore, could be said to satisfactorily desensitize. All other floorings tested desensitized from heights better than 10 feet, yielding no reactions as high as 20 to 28 feet.

To illustrate this test and its results far better than I can describe them, we have a ten-minute film composed of sequences from the high-speed cameras. We will show these on a stop-motion projector so we can look at one single frame at a time at the moment of reaction. You will note that the backboard tells in each experiment the material being tested (they are essentially the ones referred to earlier), the height, surface, angle, etc. You will see first a drop in which there was no reaction and then reactions in descending order, 5, 4, 3, 2, 2, and finally a #6, or detonation reaction. The last reaction immediately after that is a special one in which a relatively minor event grew to somewhat larger proportions over a period of several milliseconds. These films were taken at about 4000 frames per second, so that each frame therefore is a 1/4 millisecond. There is a semi-wide angle view and then a

close-up, so you can actually see the kind of reaction. You will see the fiducial light signaling time-zero as mentioned earlier, and we can count frames from then until the first evidence of reaction to give an idea of the time to reaction. We can see that #5 is a violent reaction producing a great deal of light, and looks very much like a detonation; #4 gives a bright light, but clearly shows remaining HE. Reaction #3 also produces light and you can see most of the HE flying away. The #2 reaction produces a small puff of smoke at the pole of hemisphere where it touches the pad; it can be seen from its velocity that it could not be a dust cloud or other artifact. The #6 reaction rapidly saturates the film with brilliant white light and there is nothing else to be seen.

What can we then conclude about this test? I think the principal conclusion is that its value is in it being a clear-cut test yielding sensitivity numbers of real applicability. For example, an intolerable height of drop for a particular material is immediately apparent. But it is also the proof of safing methods (soft flooring). It also gives the probable level of damage in case of an accident, even perhaps to the point of predicting whether fatalities would occur, or how much building damage would be suffered. It clearly shows the effects of different binders and other composition variables so that improvements in explosives may be made, and to reiterate it does all this with numbers needing little esoteric inference or extrapolation. On the debit side, it is an expensive test (it costs from $300 to $500 per drop, and it is not usually possible to delineate the sensitivity in fewer than four drops), it tells little about small charges, not much about response when cased, and nothing about sensitivity to shock or other high-energy or high-energy-rate inputs. (As with other sensitivity tests, however, there is a general correlation and ordering of sensitivity of various materials, but with very important exceptions).

In the future a shear friction test which we are developing may replace the skid test in part, as it is cheaper and should give similar data, and perhaps help elucidate more clearly the mechanisms of initiations in the skid test and other low-energy inputs. But we will continue to use the skid test as a screening test and final safety check for new HE materials having potential bulk use. We need to examine further the effect of different binders and other ingredients; for example, some of those found in propellants are of major interest in high explosives (and, of course, vice versa, since HMX and RDX have much use in solid propellants). In fact, tests on propellants and propellant grains would be quite interesting to us, and probably would be to many of you in this group. If there are any questions, I would be glad to try to answer them.

Mussey, SPO, DN: Have you tested the safing value of lead sheet flooring?

Akst: No, but we may do so since it is in use in many ordnance installations, and might be of direct interest to us.

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PROCESS HAZARD ANALYSIS AND SIMULATION TESTS

By

C. B. Dale
H. C. Kennedy

INTRODUCTION

Hazard analysis of processes consists of two areas:

(1) Design features of equipment and facilities based largely on standards and experience.

(2) Effect of explosives or hazardous materials when no standards are available, when it is impractical to use excessive safety factors, or to prevent loss because of the cost involved.

Hercules Powder Company at Allegany Ballistics Laboratory[1] and Rohm and Haas Company at Huntsville, Alabama,[2] have pioneered in the second area. For example, ABL has investigated in some detail the hazards of the solvent-type manufacturing process for double-base casting powder emphasizing the conditions in a mixer filled with double-base propellant matrix.

The Inert-Diluent Process as operated by the U. S. Naval Propellant Plant[3] for the manufacture of double-base propellant has been taken as an example of the second area.

DESCRIPTION OF PROCESS

The U. S. Naval Propellant Plant (NPP) became interested in the continuous inert-diluent mixing concept with the belief that it held promise for processing high-energy solid propellants in a more efficient manner and with reduced processing hazards. This has been confirmed by construction and operation of an Engineering Demonstration Plant and by small-scale safety testing at NPP.

The inert-diluent method of mixing and processing has numerous advantages over conventional methods of processing propellants. The safety advantages include the following:

(1) No mechanical mixing

(2) Remote operations

(3) Separate locations for raw ingredients plus separate location for final propellant

(4) The processing of only small quantities at any given time

(5) The use of liquid carrier as an ingredient desensitizer for the in-process streams

(6) The use of small lines to prevent detonation propagation through the lines from one location to another.

The processing concept (Figure 1) originated at Rocketdyne, a Division of North American Aviation, for composite propellant systems. Its application to the processing of double-base propellants and particularly to high-energy composite modified double-base systems is new.

In the Inert Diluent Process each major ingredient in the propellant composition is separately dispersed in a liquid carrier. The resulting slurry is continuously blended by high stream turbulence into a propellant mix. The propellant is then separated from the liquid carrier in the decanter and cast under vacuum in a mold or motor. The liquid carrier removed from the settled propellant is cycled back into the system for reuse.

A pilot-plant processing facility employing this concept has been built at NPP (Figure 2) in which single- and double-base propellant formulations have been continuously processed. The major processing problems encountered during the double-base operations dictated a change in the configuration and degree of sophistication applied to the plant. For example, the initial demonstration plant layout would not provide long process line operational data or full carrier recycle capability. In addition, the configuration of the plant neglected certain safety and design requirements of the process.

Consequently, work was initiated to renovate and expand the plant prior to composite modified double-base demonstration work. Initial shakedown of the expanded plant is currently underway.

Safety features of the modified pilot plant include the inherent safety features of the process already mentioned plus the additional safety features:

(1) Continuous, automatic sampling of the carrier at various processing points to prevent accumulation of nitroglycerin

(2) An automatically sequenced emergency shutdown interlock system.

A schematic diagram of the demonstration plant is shown in Figure 3. The two ingredient feed streams—one liquid and one solid—flow to the jet mixer where the ingredients are uniformly dispersed.

The propellant flow from the mixer can be diverted by a valve into either of two decanters. Carrier from the on-stream decanter on the right is recycled back to both dispersion points. The recycle carrier pump and the slurry pump have been modified to provide for seal and throat flush streams that prevent the possibility of solids packing in sensitive areas.

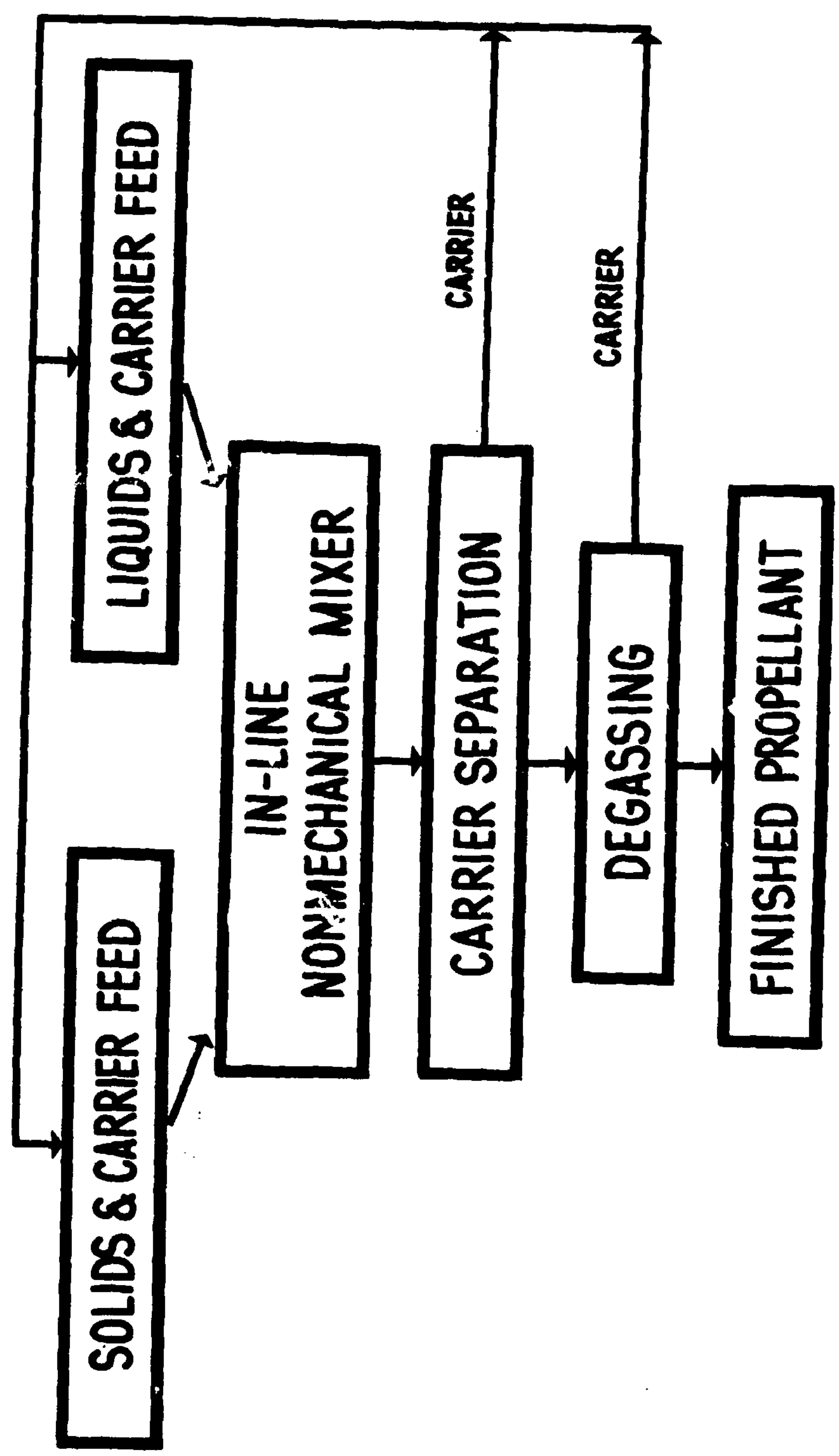

FIGURE 1. INERT-DILUENT PROCESS BLOCK DIAGRAM

FIGURE 2. AERIAL VIEW OF THE INERT-DILUENT PLANT

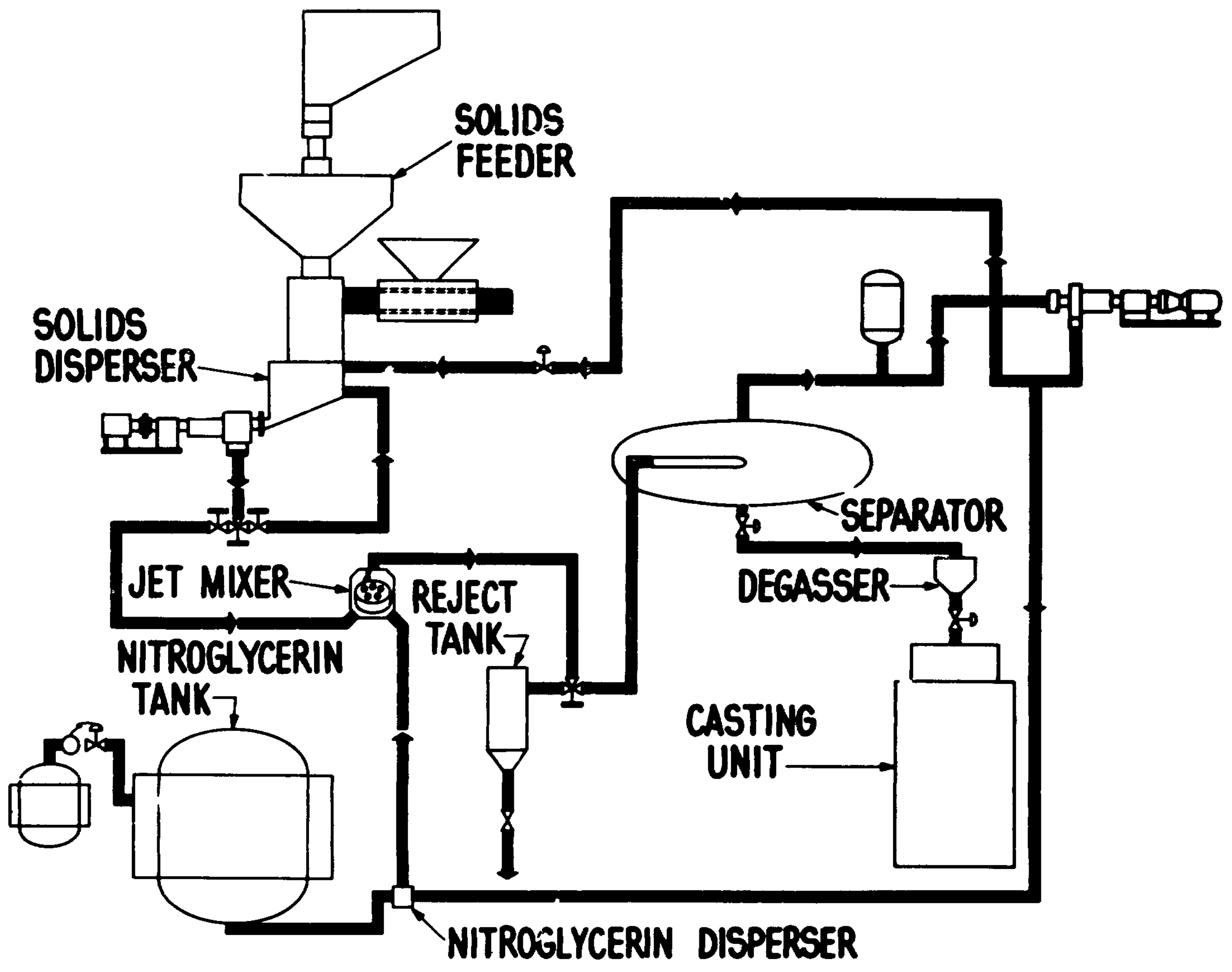

FIGURE 3. INERT-DILUENT PROCESS FLOW DIAGRAM

The heart of this mixing system is the jet mixer. It is a nonmechanical mixer. Although it is relatively small in size for its output capacity, it accomplishes a highly uniform mixing on a continuous basis. This is made possible by exploiting the turbulence of process streams. Several streams, one for each ingredient, are joined in this mixer to continuously produce a dispersion of propellant in carrier. This propellant dispersion is subsequently separated in a decanter vessel where the propellant settles to the bottom and the carrier continuously overflows from the top.

SAFETY TESTING

There are three important phases of safety testing. The first is to assure that a detonation will not travel through the long transfer lines from one raw ingredient area to another or to the casting area. The feeders for sensitive ingredients can be located remotely from each other and remotely from the casting area so that only one area of the plant would be affected in case of detonation. This advantage would be nullified if the detonation could propagate through the lines from one location to another. The second is to eliminate areas where deflagration can transit to a detonation. If a hopper of ingredients should catch on fire at the bottom, the ingredients might detonate almost immediately. Proper design will reduce the detonation hazards to a fire hazard. The third is to eliminate sources of ignition by safety testing of valves, pumps, meters, and other equipment.

Detonation-Propagation Tests

The critical diameter (largest diameter which will not propagate a detonation) was determined for each major ingredient. Each ingredient was tested while dispersed in a liquid carrier and flowing through a line. Also each ingredient was tested settled in the liquid carrier, representing a condition which would exist should pumping stop.

Initial settled-type tests were conducted by loading the ingredient and carrier into a Schedule 40 pipe, 18 inches in length, and closing each end with Saran Wrap. A Composition C-4 conical booster was placed on one end and a 1/4-inch-thick steel witness plate at the other end. Solids were allowed to settle prior to detonation of the booster. The test was designed so that a propagated detonation would result in rupture of the witness plate. Complete fragmentation of the test pipe was also considered evidence of propagation regardless of the condition of the witness plate.

Initial flowing-type tests were simulated by rotating the pipe to keep the solids in suspension. However, these tests were discontinued because of doubt about the degree of dispersion of the ingredients in the carrier.

More flowing- and settled-type tests were conducted using a Durco centrifugal pump identical to pumps used in the demonstration plant. These tests duplicated the plant conditions. To prepare a settled-type test the pump was stopped, allowing the ingredients to settle as they would should a power failure stop the pumps.

The detonation-propagation test apparatus is shown schematically in Figure 4. Figure 5 is a photograph of the apparatus and equipment used.

The ingredients were predispersed in a feed tank with an agitator. Then the dispersion of ingredient and liquid carrier was pumped through the test section and cycled back into the feed tank.

The test section consisted of two 22-foot sections of pipe attached by a right-angle elbow. The first 22-foot straight section was made up of two parts connected with a coupling 17 feet from a Composition C-4 booster charge. In the second 22-foot section of pipe, a 24-inch-diameter loop was placed about 8 feet from the right-angle elbow. A short sloping section (about 30° angle) was placed before the loop to facilitate bending the loop. The purpose of the pipe coupling, right-angle bend, and loop was to provide traps for attenuating a possible detonation. The booster was separated from the flowing sample by a 0.03-inch cellulose acetate diaphragm which withstood the line pressure and provided a minimum attenuation of the booster shock.

Prior to detonation tests on flowing streams the flow was diverted to a receiver vessel by a 3-way Durco valve. This was to prevent the detonation from propagating to the feed tank and pump. On settled-type tests the test section was disconnected from pump and feed tank prior to detonation of booster.

When testing detonation traps several steps were taken to intentionally cause propagation of a detonation. These steps were:

(1) Use of an ingredient which would propagate a detonation

(2) Settled-type test instead of flowing-type

(3) Larger diameter pipe (nominal 2-inch- or 1-1/2-inch-diameter)

(4) Larger booster 1 to 2 pounds

(5) Increased confinement (Schedule 40 pipe instead of thin wall tubing).

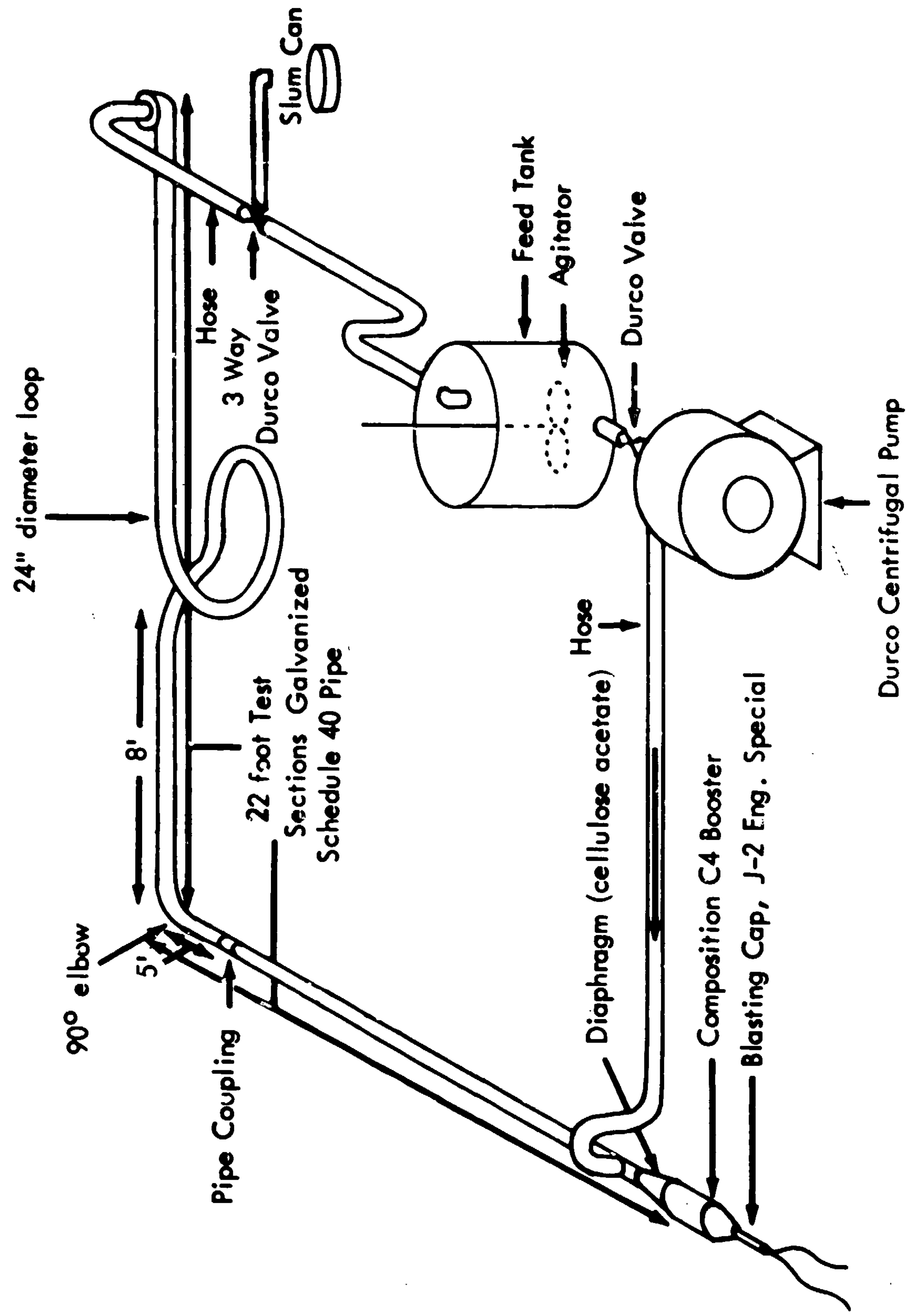

FIGURE 4. DETONATION-PROPAGATION TEST APPARATUS

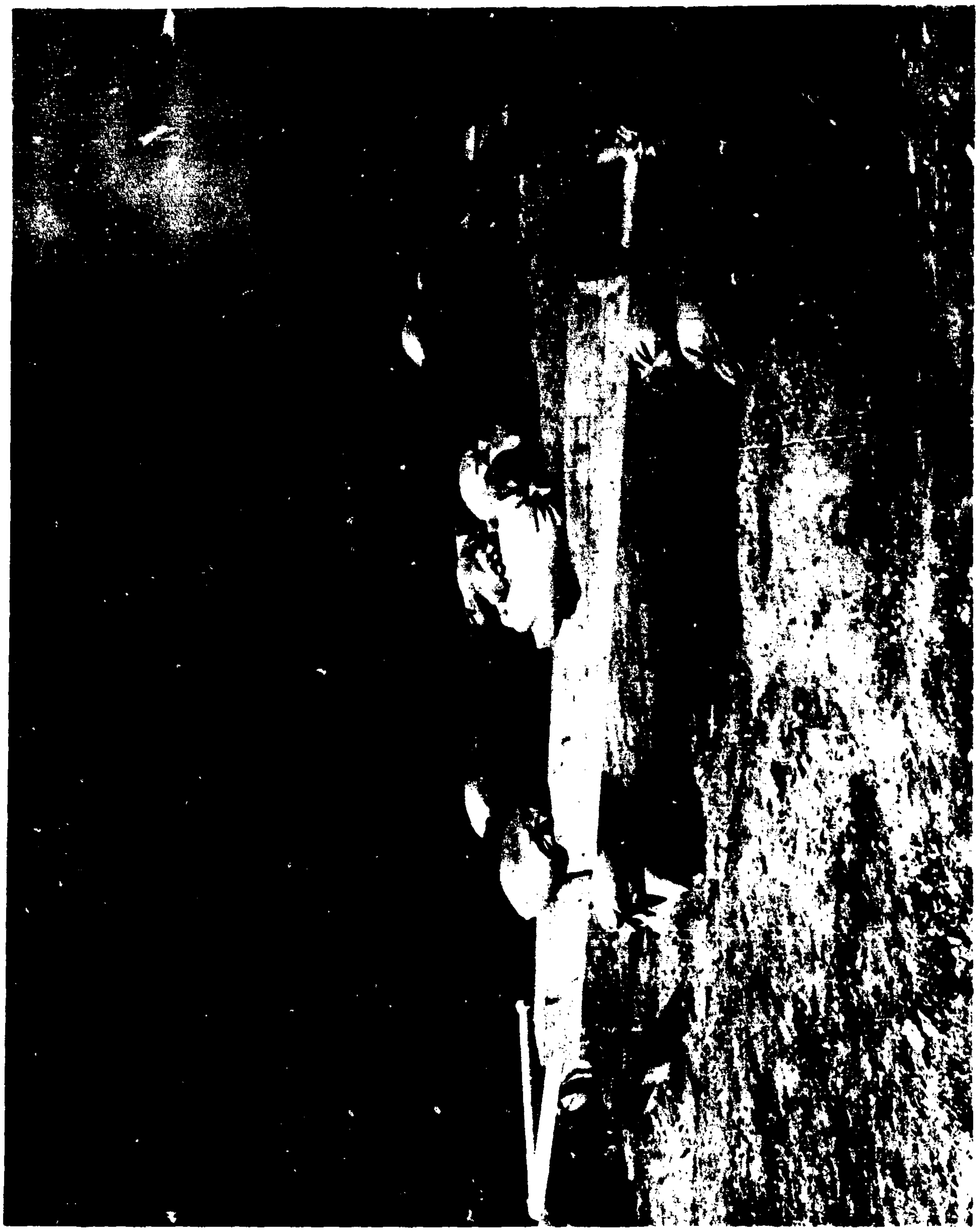

FIGURE 5. GENERAL VIEW OF DETONATION TEST EQUIPMENT

On some tests the pumping method of filling the line was replaced with a vacuum system. An arrangement of valves and a vacuum reservoir were used to pull the test dispersion from the feed tank into the test line, and the dispersion was allowed to settle. This system was used for testing combinations of ingredients in a liquid carrier when there was the possibility that such dispersions could not be pumped safely.

For detonation-propagation tests with nitroglycerin (NG), an eductor was used to disperse the NG solvent in the liquid carrier (Figure 6). The test section was copper tubing, 3/4-inch in diameter and 10 feet in length. The carrier (in this case the eductor motive fluid) was pumped to the eductor by a pressurized vessel.

Deflagration-to-Detonation Transition

Deflagration-to-detonation transition (DDT), flowing-type, tests were conducted to determine results of deflagration inside the transfer line. These tests were conducted using the same feed tank, pump, and 40-foot test section configuration as described for the detonation-propagation tests, the only exception was replacing the booster with an igniter. The igniter, called a "rod" igniter because of its shape, contained 3 grams of ABL 2056D casting powder, 3 grams of FFFG black powder, and an M1A1 Squib. These ingredients were wrapped in paper and over-wrapped with Saran Wrap in a rod shape so it could be fitted into the test pipe.

A DDT test was performed on a full-scale model of the Syntron feeder hopper (shown in Figures 7(A) and 8) to determine the result of flame initiation at the bottom of the hopper. To prevent leakage, the bottom of the hopper was welded closed. Several 7/32-inch-diameter holes were drilled in a spiral pattern around the hopper for Primacord witnesses. A 12-gram bag igniter placed in the base apex of the cone-shaped hopper was covered with 60 pounds of Olin Ball Type "A" nitrocellulose, filling the hopper to a height of 21.5 inches.

A second hopper of a modified design (Figures 7(B) and 9) was tested in the same manner. In this case 60 pounds of Olin Ball Type "A" nitrocellulose filled the hopper to a height of 10 inches.

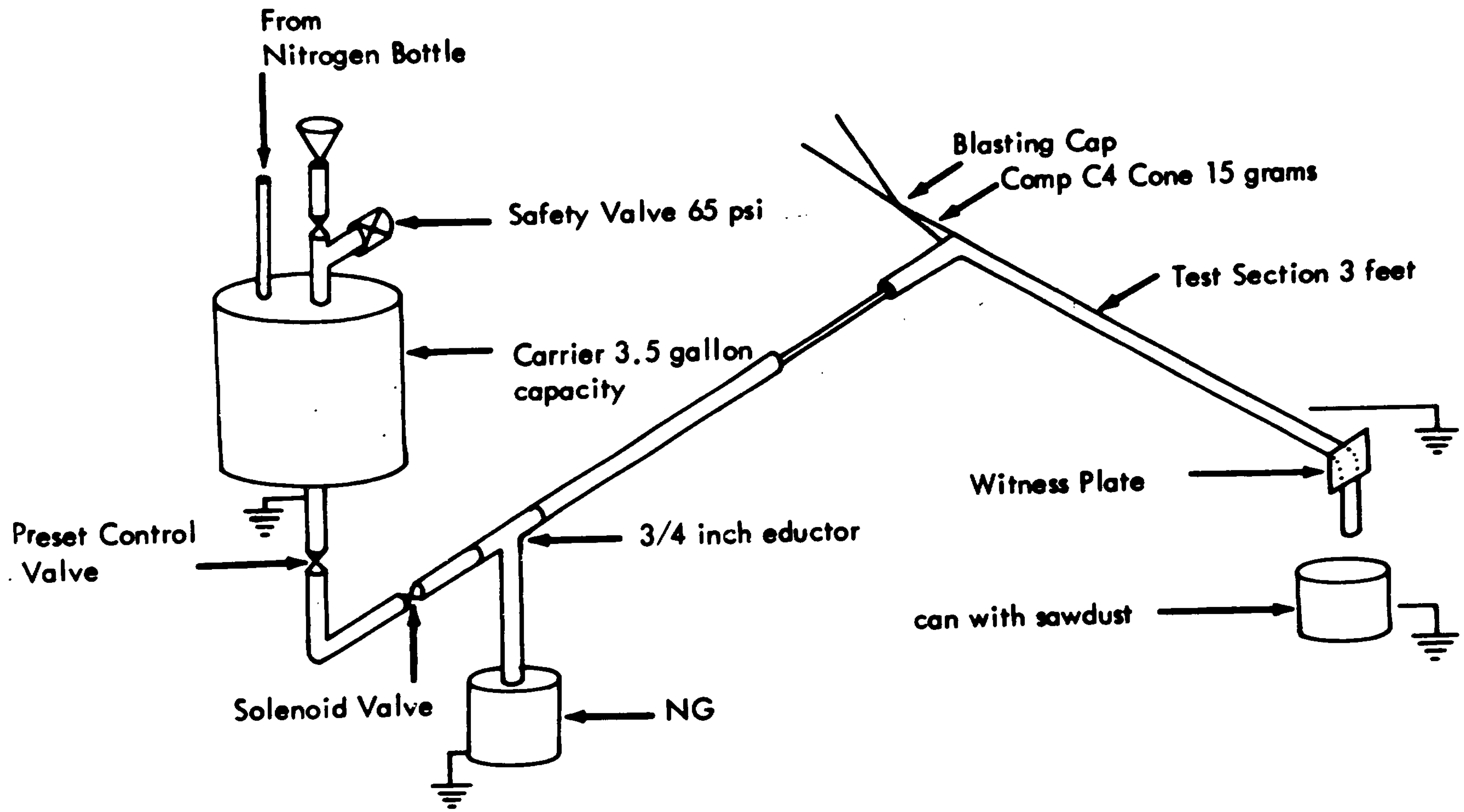

FIGURE 6. FLOW SYSTEM FOR TESTING NITROGLYCERIN

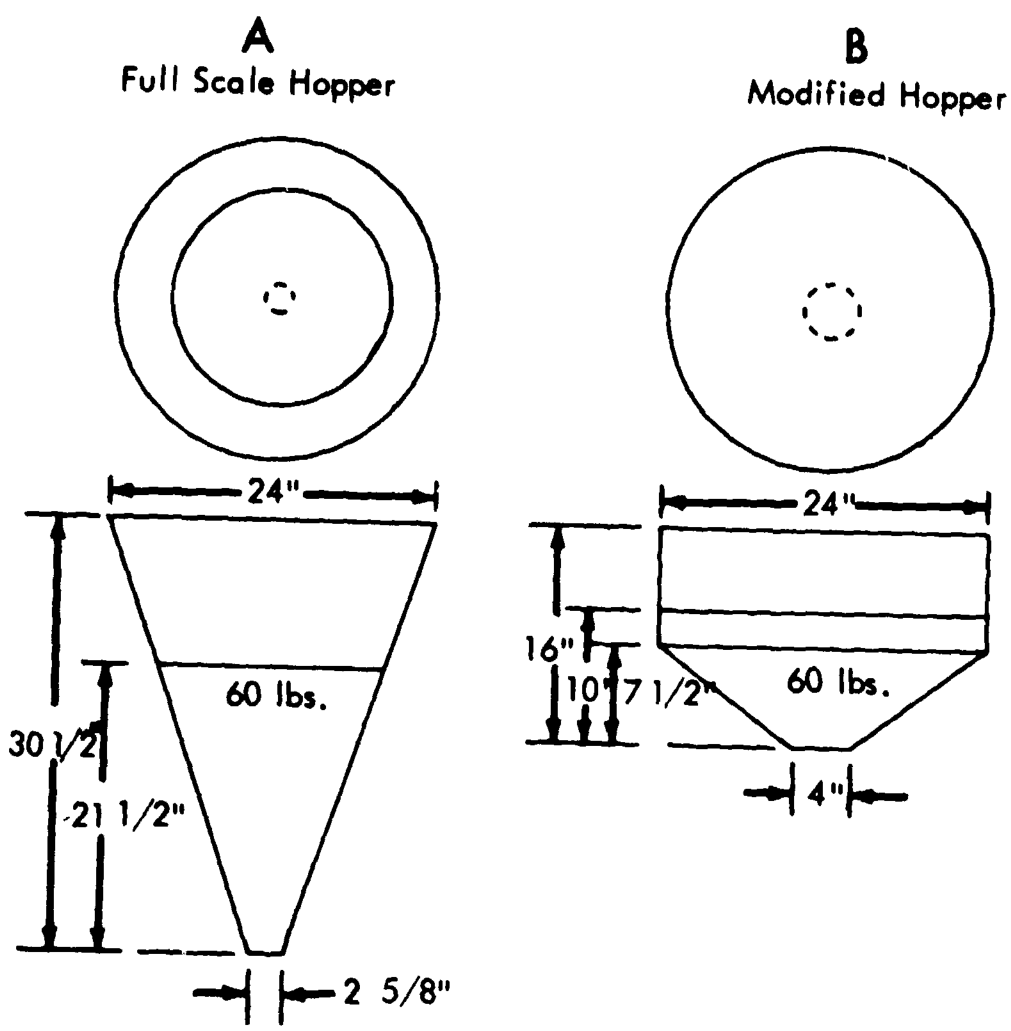

FIGURE 7. HOPPERS FOR FLAME TESTING OF OLIN BALL "A" NITROCELLULOSE

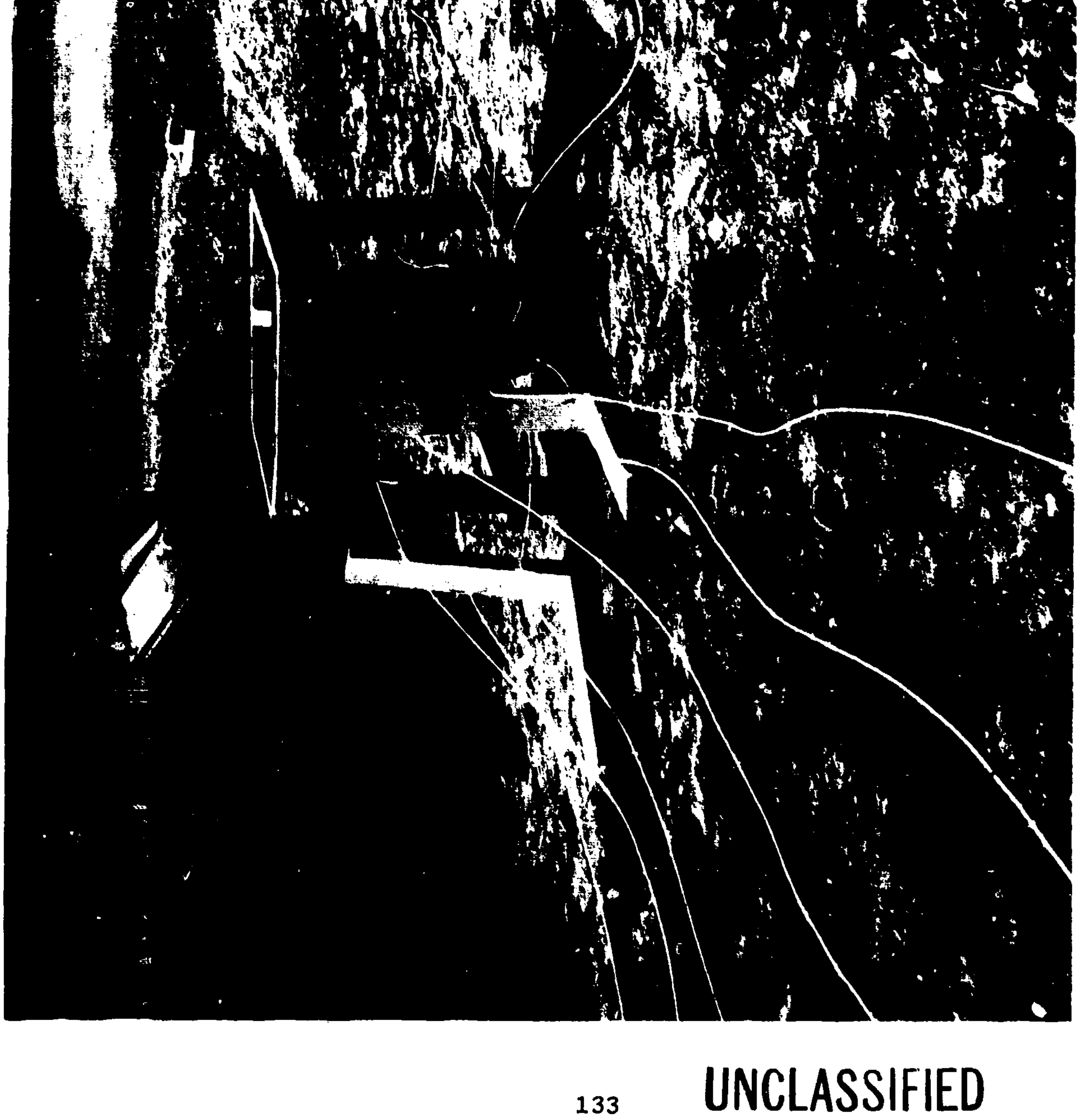

FIGURE 8. GENERAL VIEW—FULL-SCALE HOPPER BEFORE FIRING

FIGURE 9. GENERAL VIEW—MODIFIED HOPPER BEFORE TEST

Equipment Tests

To determine if a cavitation hazard existed with the Durco centrifugal pumps, one pump was modified to provide a transparent Plexiglas face plate which served as a viewing port. The test liquid, carrier tinted orange with 2-nitrodiphenylamine, was pumped under various suction and discharge head conditions while being observed visually and photographically (high-speed still camera, 1/2500-sec, and high-speed movie camera, 4000-frames/sec).

A Durco valve with a Bettis drive was actuated 100 times with several inert-diluent ingredients and with uncured propellant to prove its safe operation. This valve was a 3-way valve with a stainless steel plug which rotated in a Teflon sleeve. After each 25 actuations the valve was inspected for any visual damage or evidence of decomposition of the ingredient tested.

A Fisher Porter 3/4-inch-diameter turbine flowmeter was operated with sensitive ingredients to determine if a hazard exists. The ingredients were pumped through the meter in normal direction of flow and against normal direction of flow (a condition which might occur should a pump fail).

The Durco centrifugal pump was indirectly tested by circulating inert-diluent ingredients for detonation-propagation tests and DDT tests. The operation of this pump together with its seal and throat pump was identical to normal plant operations.

DISCUSSION OF RESULTS

It is well known that certain liquids will act as desensitizers but not necessarily enough to prevent a detonation. As an example of the desensitizing effect of a liquid, data indicate that the water content of nitrocellulose has a definite effect on lowering its sensitivity. In fact fibrous nitrocellulose is shipped 30% wet with water. It should also be apparent that solids and liquids dispersed in liquids will be less sensitive than settled-out solids and liquids.

Data obtained in detonation and flame tests made on flowing and settled streams of carrier and ingredient(s) are shown in Tables I through IV. The ingredients were divided into four groups.

(1) Nitrocellulose

(2) Oxidizers

(3) Plasticizer

(4) Fuel, oxidizer, and plasticizer.

Table I

DETONATION TESTS OF MIXTURES OF NITROCELLULOSE AND CARRIER

Mixture (wt %)			Condition of test	Pipe diameter (in.)	Results	Trap[1]
NC	Fuel	Hydrocarbon carrier				
20	-	80	Settled	2.0	2+	Elbow, loop
18	2	80	Settled	2.0	1+, 1-	Elbow
20	-	80	Flowing	2.0	2-	-
20	-	80	Flowing[2]	1.25	2-	-
30	-	70	Settled	0.5	1+, 2-	-
30	-	70	Settled	0.75	3+	-
100[3]	-	-	Settled	0.25	+	-

[1]Detonation arrested at these locations.
[2]DDT test.
[3]Allegany Ballistics Laboratory, personal communication to C. B. Dale.

Table II

DETONATION TESTS ON MIXTURES OF OXIDIZER AND CARRIER

Mixture (wt %)			Condition of test	Pipe diameter (in.)	Results
AP	HMX	Hydrocarbon carrier			
20	-	80	Settled	1.25	2-
-	20	80	Settled	1.25	2-
-	100	-	Settled	0.17	1+
-	96	4[1]	Flowing	0.12	3-
-	96	4[1]	Flowing	0.31	1+
20	-	80	Flowing[2]	0.75	2-
-	25	75	Flowing[2]	0.75	1-

[1] In this case carrier was nitrogen.
[2] DDT test.

Table III

DETONATION TESTS ON MIXTURES OF NITROGLYCERIN AND CARRIER

Mixture (wt %)				Condition of test	Pipe diameter (in.)	Results
100% NG	90% NG + 10% TA	75% NG + 25% TA	Hydrocarbon carrier			
	-	25	75	Flowing	0.75	2-
-	20	-	80	Flowing	0.75	3-
-	20	-	80	Settled	2.0	2+
60	-	-	40[1]	Flowing	1.0	4-

[1]In this case carrier was water; tests reported in an informal report, Biazzi Co., Switzerland, Schlehbusch tests.

Table IV

DETONATION TESTS ON MIXTURES OF INGREDIENTS AND CARRIER

Mixture (wt %)					Condition of tests	Pipe diameter (in.)	Results
NG	NC	Oxidizer	Fuel	Hydrocarbon carrier			
-	7	6	7	80	Settled	2.0	2-
-	4	10	6	80	Settled	2.0	2-
-	-	65	-	35	Settled[1]	0.5	3-
-	←20→			80	Flowing[2]	1.0	3-
←20→				80	Flowing[2]	1.0	3-

[1]Vertical.
[2]ABL, personal communication to C. B. Dale.

The tests were designed to show that pipelines could be sized such that there would be little likelihood of propagating a detonation. As a part of this aim, detonation traps were included in the test equipment. Further, the lines were long enough to allow for the possibility of attenuating a detonation in any of the possible mixtures.

Nitrocellulose-Carrier

The largest line size tested included a "safety factor" because the diameter of 2 inches was about 10% larger than the line size in the proposed production plant. For a dispersed mixture of 20% by weight Olin Ball "A" and carrier in a 2-inch-diameter line, the results as shown in Table I were negative, i.e., the line was ruptured for only a few inches from the booster.

A 20% by weight nitrocellulose-carrier mixture allowed to settle out in a 2-inch-diameter pipe propagated a detonation. In one case a 90° elbow stopped the detonation; in another case the detonation was stopped at a sloping section in which the carrier and nitrocellulose had separated. In this case, however, the elbow failed to stop the detonation as shown in Figure 10.

The effect of concentration of settled nitrocellulose was estimated from the data for nitrocellulose mixed with one or two other ingredients, either fuel or oxidizer or both. It is assumed that the other ingredients will result in a more severe case. Hence, using the data for mixed ingredients, it is found that for a mixture containing 7% by weight of nitrocellulose no detonation will occur. Similarly for a mixture containing 18% by weight of nitrocellulose a detonation did occur. Conservatively, a mixture of 10% nitrocellulose in 90% of carrier should not propagate a detonation when settled out.

Another approach to reduce the probability of propagation of a settled mixture in a pipe is to reduce the pipe diameter. For a composition of 30% by weight nitrocellulose, settled out, the critical diameter is less than one-half of an inch. For comparison, the critical diameter of dry nitrocellulose is less than one-quarter of an inch.

A flame test was made on a flowing stream of 20% by weight of nitrocellulose. The result was negative.

Oxidizer and Carrier

Negative results were obtained in 1-1/4-inch-ID pipe for a 20% by weight settled mixture of ammonium perchlorate in the carrier as shown in Table II. The same holds true for a 20% by weight mixture of HMX.

Flame tests were made on dispersions of 20% by weight of ammonium perchlorate in heptane in a 3/4-inch pipe. The results were negative. These conditions were repeated with HMX and again the results were negative. The flame tests are confirmation that the critical diameter is greater than three-quarters of an inch and that the flame is extinguished rather than being carried along by burning suspensions of ammonium perchlorate or HMX in heptane.

In the case of HMX a pneumatic conveying system was considered. Detonation tests were made on dilute suspensions of dry HMX in nitrogen with a concentration of 4% of HMX by volume. In a 1/8-inch steel pipe the detonation test was negative. While thin-wall plastic tubing will act as a pressure relief device it was not sufficient to reduce the shock to a level where it would not initiate a concentration exceeding 4% by volume.

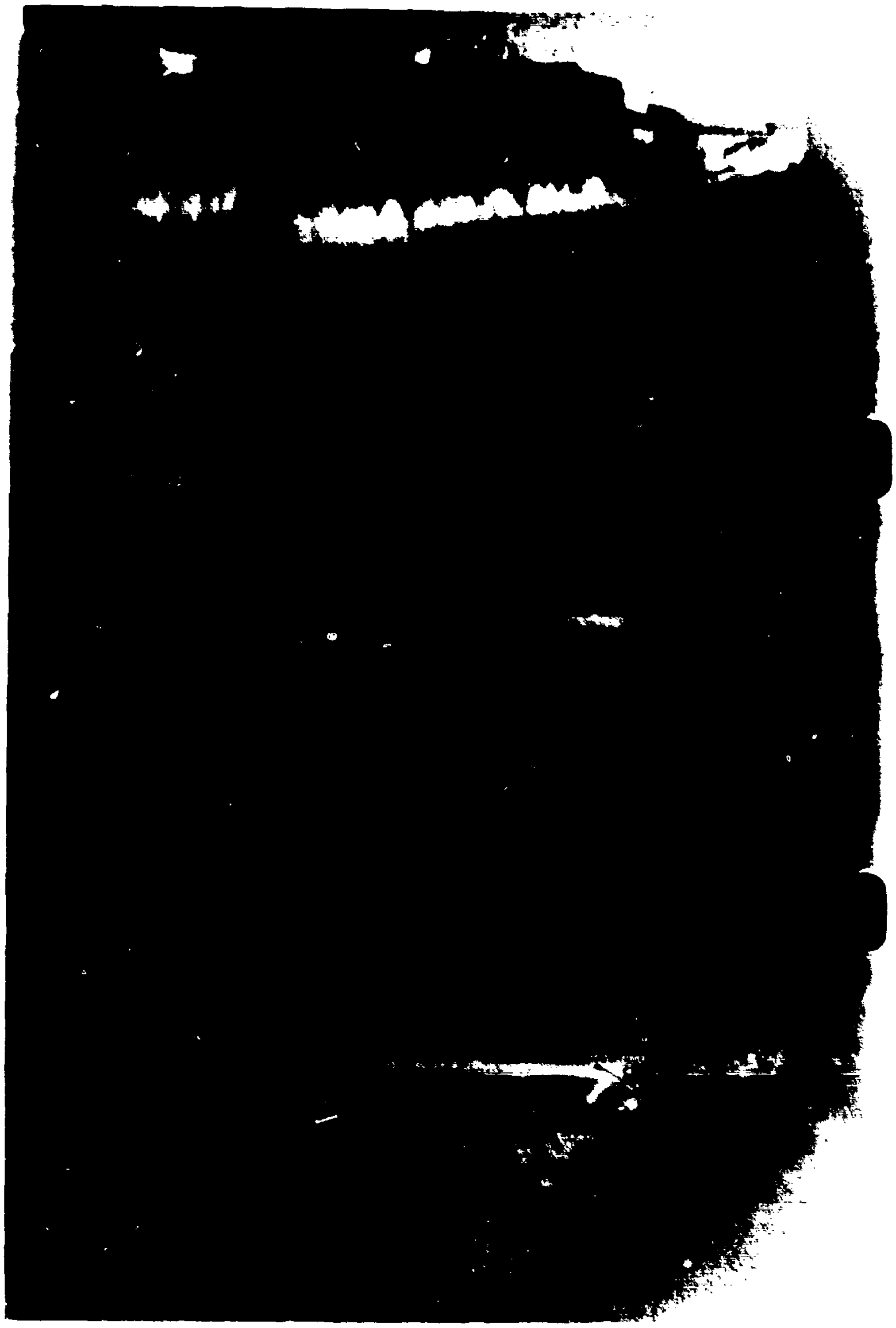

FIGURE 10. DETONATION-PROPAGATION TEST OF OLIN BALL "A" NITROCELLULOSE

Nitroglycerin and Carrier

Tests with streams containing 60% by weight of nitroglycerin and 40% by weight water showed that a detonation would not propagate through a 1-inch pipe (Table III). With a hydrocarbon carrier and a 25% by weight concentration of nitroglycerin in a 3/4-inch steel pipe, a detonation could not be propagated (Figure 11). The data for settled nitroglycerin were incomplete but it is expected that a positive result would be obtain at a pipe diameter of less than 1/2 inch by comparison with the data for nitrocellulose.

Mixed Ingredients and Carrier

Settled ingredients without nitroglycerin as shown in Table IV did not propagate detonations in 2-inch-diameter pipes. Ingredients with nitroglycerin were dispersed in a 1-inch-diameter pipe; again no detonation was propagated. The effect of oxidizers is believed to be to increase the susceptibility to a detonation but apparently not sufficiently to propagate a detonation in the present cases.

Detonation Traps

Six types of detonation traps have been considered and some of these have been tested. The types that have been considered are as follows:

(1) Pipe coupling

(2) 90° elbow

(3) 360° pipe loop

(4) Vertical pipe section (for settled condition)

(5) Small diameter pipe

(6) Precompression

The first three types have all been found to be partially effective but not fully reliable. Tests have been recorded where the coupling, the 90° elbow, and the complete loop have been able to stop a detonation. However, the only types that are acceptable for the present application are the vertical section of pipe or a pipe with a diameter smaller than the critical diameter of the particular composition being considered.

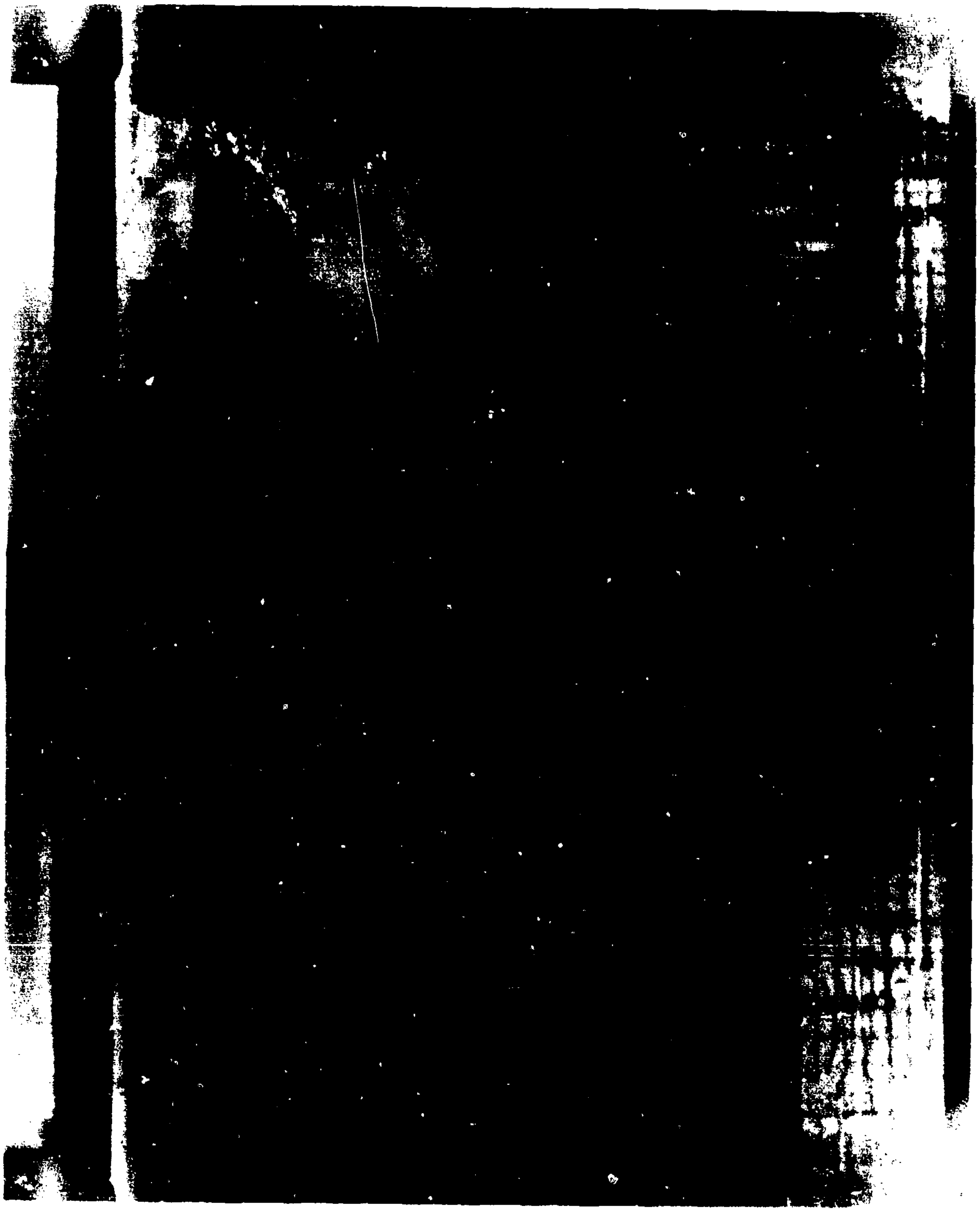

FIGURE 11. NEGATIVE DETONATION TEST OF NITROGLYCERIN

The sixth method has been explored by Naval Ordnance Laboratory and in some instances it has had successful application in the 360° loop.

Hopper Tests

Two types of hoppers were investigated to determine the effect of flame initiation of nitrocellulose. One hopper had a 36° cone and the other 106° (Figures 7, 8, and 9). The charge of 60 pounds nitrocellulose was ignited by a bag igniter. As shown in Figures 12 and 13 the more confined hopper had a more intense fireball as expected and suffered greater damage but there was no detonation. It has been standard practice to judge the transition probabilities of vessels on the basis of the outlet diameter which is mostly too far on the safe side. It has resulted in economic and possibly process penalties.

Cavitation Tests

The Durco pump which recirculates hydrocarbon carrier and nitrocellulose has been used elsewhere to recirculate HMX and water slurries. It was recognized that a detonation hazard could exist if the pump were to cavitate. High-speed photographs were taken fo the pump operating normally and with severely restricted suction as shown in Figures 14 and 15. On the basis of these tests it was concluded that there exists a good margin of safety in the operation of these pumps.

Application of Test Results

A simplified flow diagram shows the most important line sizes for the Pilot Plant and Table V gives an analysis of the explosive hazards of the various lines. Line sizes for all solids either individually or mixed are judged safe from propagating a detonation. In the case of the nitrocellulose settled in the line, a trap consisting of a vertical section of pipe is acceptable. The same is true for settled ingredients including nitrocellulose. For transition from deflagration to detonation in a pipe with settled nitrocellulose or a mixture of solid ingredients there are no data. However, any detonation could be arrested by a vertical pipe.

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FIGURE 12. FULL-SCALE HOPPER AFTER DDT TEST

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FIGURE 13. MODIFIED HOPPER AFTER DDT TEST

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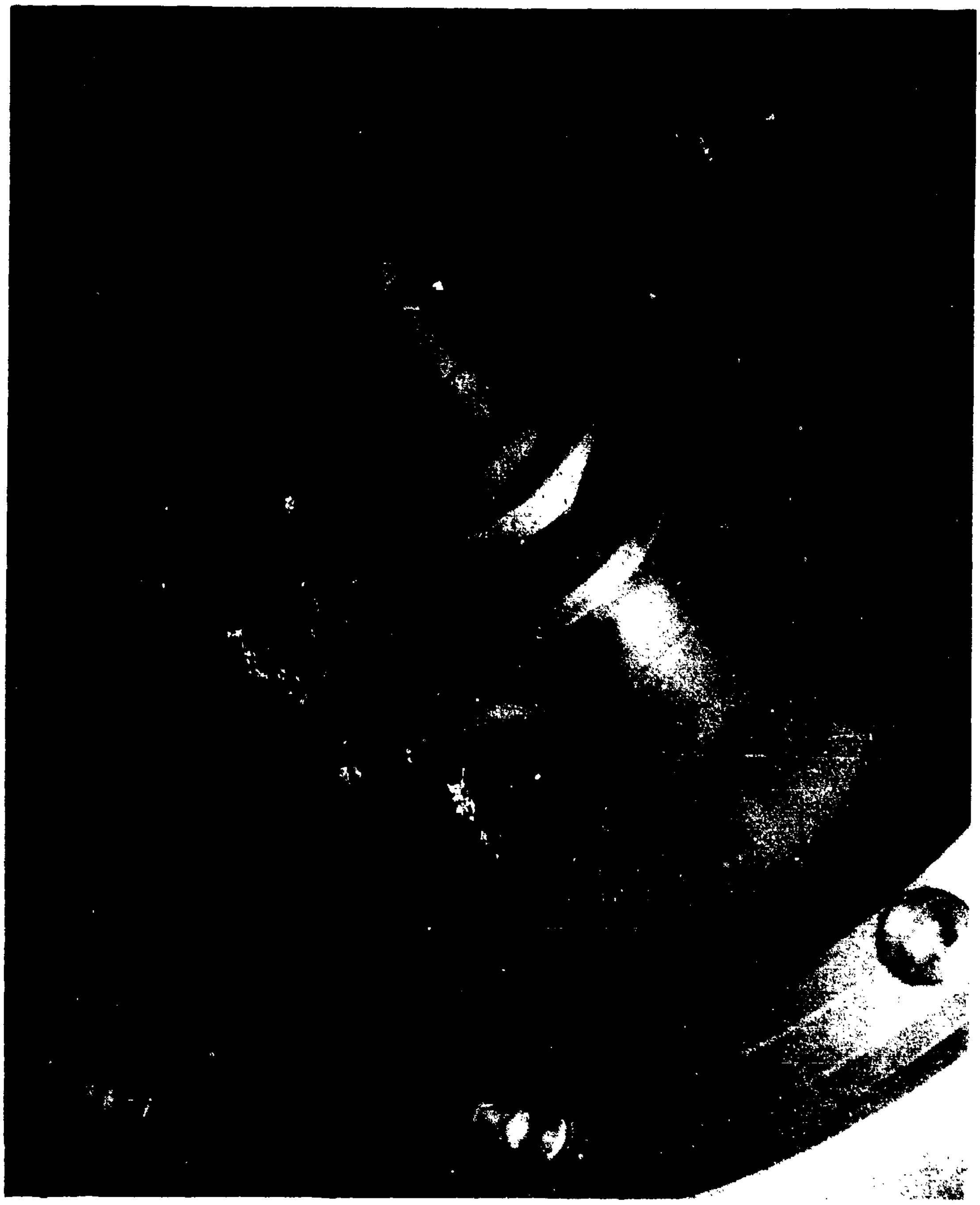

FIGURE 14. NORMAL OPERATION OF PUMP

FIGURE 15. CAVITATION IN A PUMP

Table V

ANALYSIS OF CRITICAL DIAMETERS OF PROCESS LINES

Mixture	Pipe diameter (in.)	Detonation-propagation		Deflagration-to-detonation transition
		Flowing	Settled	
NC/C	0.652	OK	Adequate[1]	Adequate
AP/C	0.652	OK	OK	OK
HMX/C	0.652	OK	OK	OK
NC/Al/C	0.652	OK	OK	OK
HMX/AP/C	0.652	OK	OK	OK
All solids/C	0.902	OK	Adequate[1]	Adequate
Prop/C	0.777	OK	Undefined	Undefined
NG/C	0.777	Undefined	Adequate[1]	Undefined

[1] By means of a trap.

For nitroglycerin the data are limited for detonation tests with nitroglycerin dispersed in hydrocarbon carrier. However, dispersed nitroglycerin in water will not propagate in a 1-inch pipe. Hence, while listed as undefined it is highly improbable that a detonation would be propagated. Similarly, for the settled out nitroglycerin in a vertical pipe, data are incomplete but there is some evidence that the settled out material will transmit a relatively weak shock through the hydrocarbon carrier.

For the flowing propellant the data show no hazard but for the settled material in a horizontal pipe the hazard is undefined. Hence, the result for a flame initiation is also "undefined." When the propellant has been settled out in the "decanting chamber" a definite detonation hazard exists.

A similar analysis has been made for the lines in the proposed Production Plant.

CONCLUSIONS

Extensive testing has been carried out to simulate hazards in a pilot plant and a production plant. It has enabled management to have confidence in the elimination of detonation hazards wherever possible. In some cases it has permitted a reduction in costs when a material was shown to be a Class "B" hazard instead of Class "A."

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(3) U. S. Naval Propellant Plant. DEVELOPMENT OF THE INERT-DILUENT CONCEPT FOR THE MANUFACTURE OF DOUBLE-BASE AND COMPOSITE-MODIFIED DOUBLE-BASE PROPELLANTS, VOL. II. SINGLE- AND DOUBLE-BASE PROPELLANT PROCESSING (U). By D. H. Carstater, <u>et al</u>. TMR 216. 1 July 1964. CONFIDENTIAL.

MACHINING STUDIES OF FLUOROCARBON, COMPOSITE, AND DOUBLE-BASE PROPELLANT SYSTEMS

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ABSTRACT. The behavior of six different propellant systems (three fluorocarbon, two cast composite, and one double-base) under various machining conditions was investigated. It was determined that the temperature rise experienced by a grain during machining is an exponential function of the revolutions per minute (rpm), and a linear function of the feed rate over the range investigated. The product of the grain diameter and cut size can be used to predict the severity of the machining operation as well as temperature.

CO_2, N_2, air, and Freon 113 were evaluated as coolants for the machining of a fluorocarbon system. All coolants operated adequately; however, Freon 113 exhibited superior cooling qualities.

The propellant systems investigated were machined up to 1,000 rpm without ignition or extreme temperature buildup (the cut was 0.075 in. on the radius of a 0.75-in. diameter sample). The temperatures obtained for each sample were in the same order as the Allegeny Ballistics Laboratory (ABL) friction tester; i.e., the most sensitive propellant system reached the highest temperature, the least sensitive propellant system reaching the lowest temperature for a given set of machining conditions. This indicates that the ABL friction tester is able to qualitatively predict sensitivities in regard to machining. (UNCLASSIFIED)

INTRODUCTION

At best, the machining of propellant systems is hazardous. Several experiments were conducted in an attempt to gain insight into the behavior of various solid propellant systems during the machining operations. The experiments were designed to obtain information on effectiveness of various coolants, temperature rise of the grain as a function of operating variables, and ignition conditions.

It was felt that sufficient data would be generated during these tests to determine if a standard friction test (ABL friction test) is able to predict the sensitivity of propellant as related to the machining operation.

Six different propellant systems (three fluorocarbon, two cast composite, and one double base) were examined. The sample size varied with the composition, as follows:

	Propellant	Diameter, in.
1.	PL 6301 - fluorocarbon	4.630
2.	RG 6142.2 - fluorocarbon	3.012
3.	PL 6503 - fluorocarbon	0.760
4.	E-107 - composite	8.702
5.	C-55A - composite	5.875
6.	X-14 - double base	5.040

EVALUATION OF COOLANTS

The initial phase of the experiment was to determine the ability of various coolants to act as a temperature depressant. Temperature measurements for all of the experiments were obtained using a Bristol Dynamaster temperature recorder and a chromel-alumel thermocouple embedded slightly below the cutting edge of the tool bit.

CO_2, N_2, air, and Freon 113[1] were used as coolants during the machining of PL 6301 fluorocarbon. CO_2 and N_2 were supplied from compressed gas tanks under 1,500 pounds per square inch gage (psig) for the N_2 and 700 psig for the CO_2. The air was supplied by a compressor which yielded a line pressure of 100 psig. The estimated nozzle pressures for the CO_2, N_2, and air were 10 to 15 pounds per square inch (psi). The Freon was supplied by a coolant mist generator.

[1] E. I. du Pont de Nemours & Co., Inc., Wilmington, Delaware.

Starting with an initial fluorocarbon-grain diameter of 4.63 in., five successive OD cuts of 0.125, 0.150, 0.175, 0.200, and 0.250 in. were made. The rpm and feed rate were kept constant at 122 rpm and 0.18 in/rev; the cut was 2.4 in. in length.

The maximum temperature was reached during the final 0.250 in. cut with a diameter of 3.33 in. The temperature was 130 degrees Fahrenheit (°F) for the CO_2, N_2, and air cooled operations. During the Freon cooled machining operation, the temperature reached 125°F. Without the use of coolants the temperature reached 150°F for identical cut and diameter conditions. Table 1 summarizes the work done.

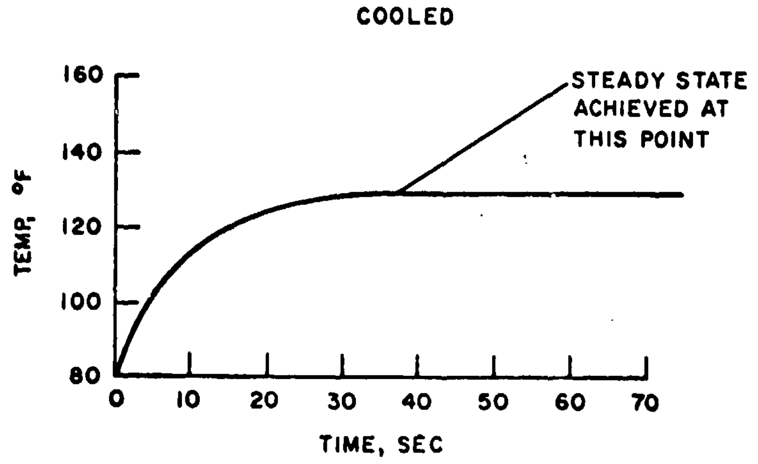
TABLE 1. Effects of Various Coolants

Diameter, in.	Cut size, in.	N_2, °F	CO_2, °F	Air, °F	Freon, °F	No coolant,[a] °F
4.63	0.125	112	115	118	105	135
4.38	0.150	112	114	110	105	135
4.08	0.175	110	120	112	110	140
3.73	0.200	120	125	120	115	145
3.33	0.250	130	131	130	125	150

[a] Equilibrium not reached.

The temperature depressant effect of CO_2, N_2, and air are approximately equal. The temperature was lowered an additional 5 to 13°F with the use of Freon 113, which is considered a more efficient coolant.

It is interesting to note the difference between a cooled and uncooled machining operation in regard to the rate of temperature increased. The temperature increase for an uncooled system is continual for a machining operation which has a 70 sec duration. However, the cooled system reaches a lower steady state temperature after about 40 sec (Fig. 1).



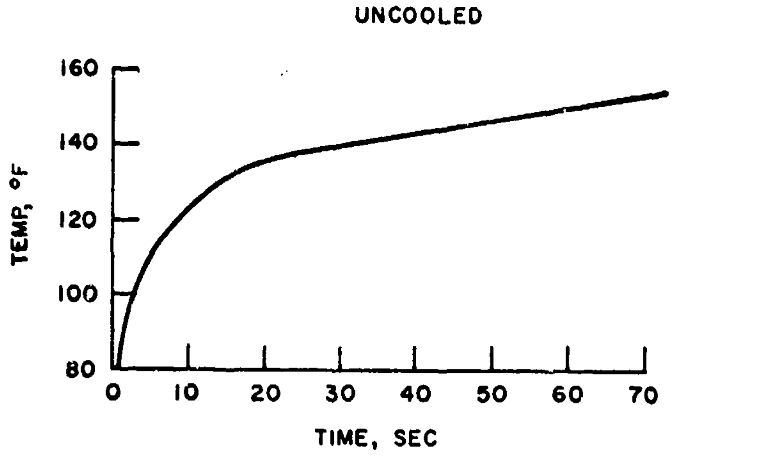


FIG. 1. Temperature versus Time Curves for Cooled and Uncooled Propellant.

RELATIONSHIP BETWEEN TEMPERATURE AND OPERATING VARIABLES

PL 6301 FLUOROCARBON

The second phase of the work determined the effect of operating variables (rpm, feed rate, and cut size) on the temperatures which the grain experienced during the machining operation.

The first propellant investigated was PL 6301, a relatively insensitive fluorocarbon with the following composition: 19.5% Aluminum (AL), 15% Viton A, 15% Teflon, 49.5% ammonium perchlorate (AP), and 1% sodium fluoride.

The initial grain diameter was 4.63 in. Five successive cuts were made on the diameter: 0.125, 0.150, 0.175, 0.200, and 0.250 in. (the cut was 2.4 in. long). The feed rate was held constant at 0.018 in/rev. Three sets of grains were machined at 122, 153, and 202 rpm. The data is plotted in Fig. 2 and tabulated in Table 2. A linear relationship exists between temperature and rpm (approximate relationship for range covered).

It should be noted that the exterior surface of an extruded fluorocarbon grain does not exhibit the same properties as the rest of the grain. Consequently, the data obtained from the first cut in each grain is not representative of the temperature data obtained during machining of the remaining protion of the grain. The temperatures are approximately 10°F higher than expected.

The temperature-rpm relationship is ordered by the product of diameter and cut size; i.e., machining of a grain with a diameter of 3.73 in. and a cut size of 0.200 in. is less severe than machining a grain with a 3.33 in. diameter and a cut size of 0.250 in. Figure 3 is a plot of temperature versus diameter times cut size for various machining conditions.

Data was obtained which related the temperature to feed rate for three different diameters and cut sizes; this relationship is linear (Fig. 4).

In order to investigate parting of the grains, 1/4-in. slabs were cut with a parting tool having a thermocouple embedded below the cutting edge. Cuts were made at various rpm and feed rates (Table 3). No attempt was made to obtain a relationship between temperature and operating variables; it was only desired to determine the magnitude of temperatures that the grain experiences during this operation.

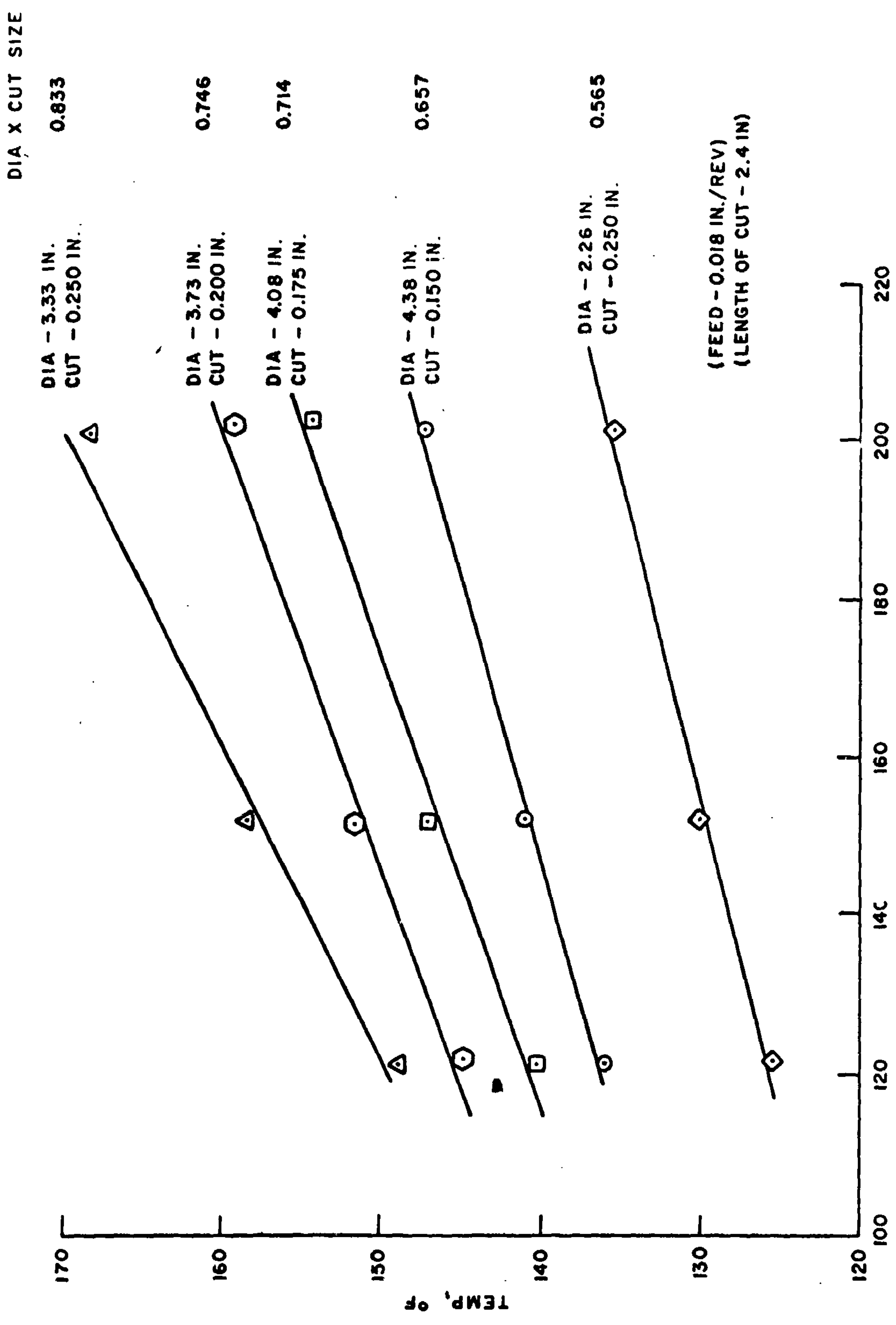


FIG. 2. Temperature versus Rpm - PL 6301.

TABLE 2. Machining of PL 6301 Without Coolant

Diameter, in.	Cut size, in.	Length of cut, in.	Feed, in/rev	Diameter times cut, in.	Rpm	Temp, °F	Rpm	Temp, °F	Rpm	Temp, °F
4.63	0.125	2.4	0.018	0.579	122	136	153	144	202	147
4.38	0.150	2.4	0.018	0.657	122	136	153	141	202	147
4.08	0.175	2.4	0.018	0.714	122	140	153	147	202	154
3.73	0.200	2.4	0.018	0.746	122	145	153	152	202	159
3.33	0.250	2.4	0.018	0.833	122	149	153	159	202	168
2.26[a]	0.250[a]	2.4[a]	0.018[a]	0.565[a]	122[a]	125[a]	153[a]	130[a]	202[a]	135[a]

[a]This data obtained at a later date.

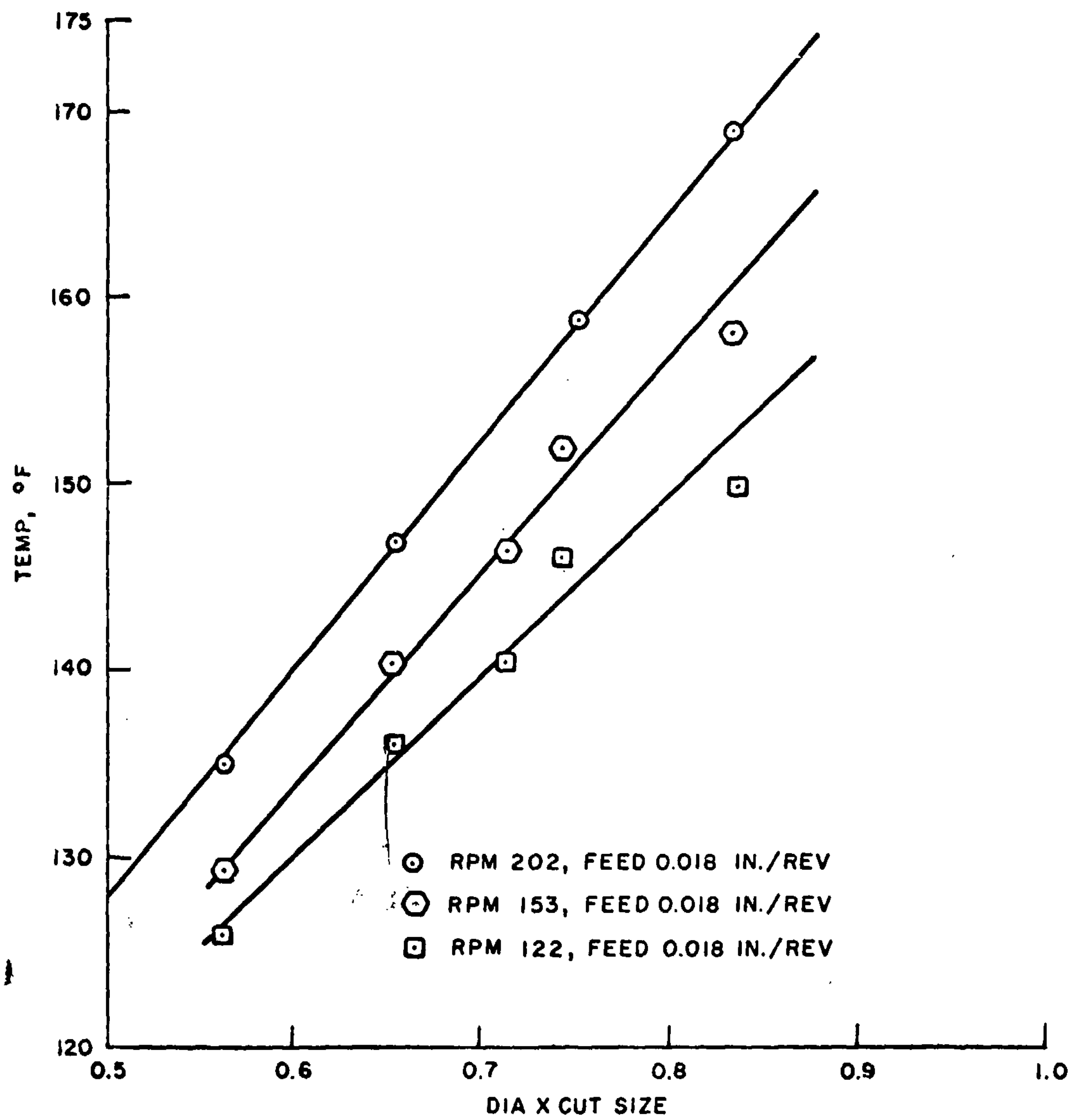


FIG. 3. Temperature versus Diameter Times Cut Size - PL 6301.

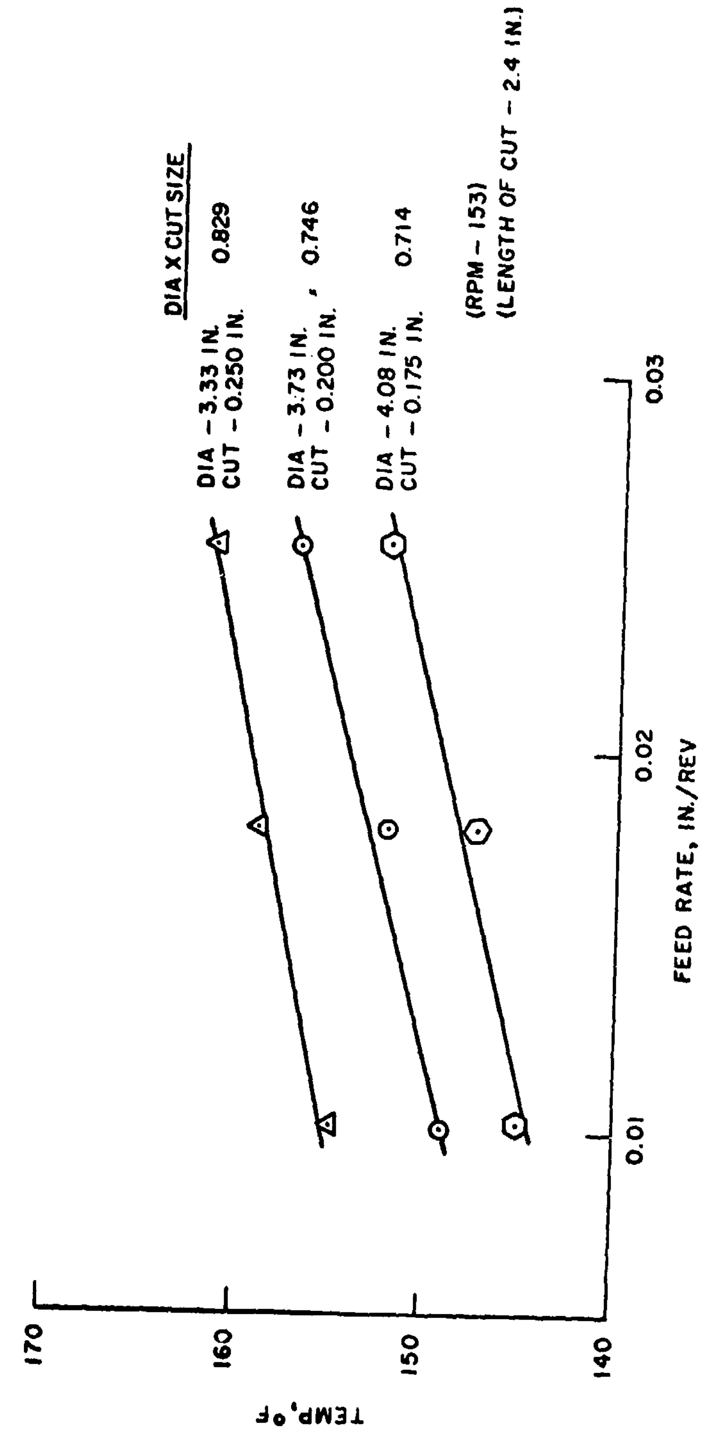


FIG. 4. Temperature versus Feedrate.

TABLE 3. Temperature Obtained During the Parting of Fluorocarbon PL 6301

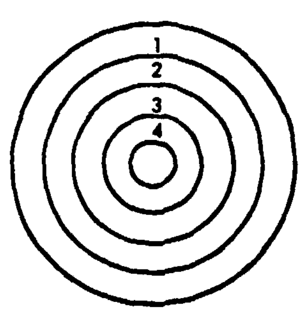
Rpm	Diameter, in.	Feed, in/rev	Temp, °F
122	4.200	0.010	109
153	4.200	0.010	115
202	4.200	0.010	121
122	4.200	0.255	119
122	2.83	0.010	101
122	4.200	0.018	112

RG 6142.2 - FLUOROCARBON

A cylindircal sample of RG 6142.2 (23% Viton A, 44.4% AP, and 32.6% zirconium (Zr)) with a 3.012 in. initial diameter was machined at 122, 153, and 202 rpm. The feed rate was held constant at 0.018 in/rev. Four consecutive cuts of 0.125, 0.150, 0.200, and 0.250 in. were made (the cut was 2.4 in. long). The data is plotted in Fig. 5 and tabulated in Table 4.

A linear relationship exists between temperature and rpm. However, the linear relationship between temperature and diameter times cut size, as noted in the previous machining study of PL 6301, does not exist. Note in Fig. 5 that the diameter times cut size number does not order the temperature-rpm relationship as it did in Fig. 2.

The temperature-diameter times cut size relationship was not linear due to non-uniform propellant. Shore hardness readings were obtained in the areas of the cuts and the results were:



Cut	Shore hardness
1	80
2	87
3	91
4	90

The first two cuts were made on softer propellant than the last two cuts; consequently, lower temperatures were obtained.

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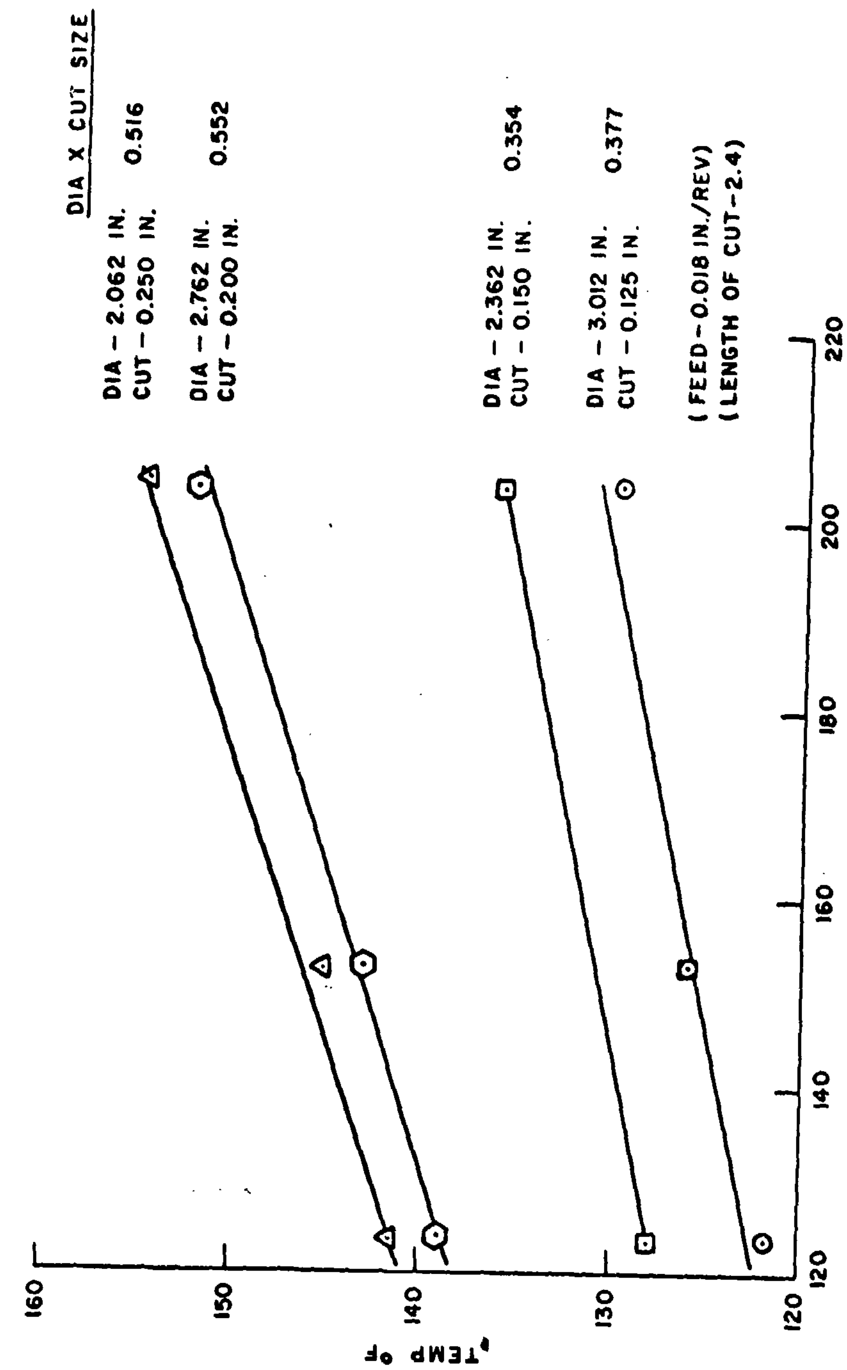

FIG. 5. Temperature versus Rpm - RG 6142. 2.

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TABLE 4. Machining of RG 6142.2

Diameter, in.	Cut size, in.	Length of cut, in.	Feed rate, in/rev	Diameter times cut, in.	Rpm	Temp, °F	Rpm	Temp, °F	Rpm	Temp, °F
3.012	0.125	2.4	0.018	0.377	122	122	153	126	202	130
2.762	0.200	2.4	0.018	0.552	122	139	153	143	202	152
2.362	0.150	2.4	0.018	0.354	122	128	153	126	202	136
2.062	0.250	2.4	0.018	0.516	122	142	153	145	202	155

PL 6503 - FLUOROCARBON

PL 6503, an extremely sensitive fluorocarbon propellant system, was the last fluorocarbon to be investigated. It contains 54%, 3 to 5 μ, magnesium (Mg), 30% Teflon, and 16% Viton A.

The propellant which was machined at 91, 122, and 153 rpm had an initial diameter of 0.760 in. The feed rate was kept constant at 0.01 in/rev; the cut was 2.4 in. long.

The machining conditions used for the experiment were more severe than those used in daily operations. No ignition of the propellant occurred. This is mentioned due to the fact that ignition of this propellant system had occurred in the past during a routine machining operation. It also points out that the variables under study are not the only ones that are critical; factors such as tool bit sharpness, location of the tool bit when machining is begun, foreign matter in the propellant, and machining techniques in general are also critical.

The data for the machining of PL 6503 is plotted in Fig. 6 and tabulated in Table 5. The relationship between temperature and diameter times cut size is linear for this system.

X-14- DOUBLE-BASE PROPELLANT

X-14 is a double-base propellant system containing 48% nitrocellulose (12.6% N), 44.5% nitroglycerin, 0.4% P_1 N-propyladipate, 2.0% 2-nitrodiphenylamine, 2.5% mono basic cupric salicylate, 2.5% mono basic lead β resorcylate, and 0.1% candelilla wax. This system was studied to determine if the relationship between temperature and diameter times cut size which was found to be linear for the fluorocarbon systems, is also linear for this double-base system.

The propellant machined was cylindrically shaped, with an initial diameter of 5.040 in. Seven successive cuts were made as noted in Table 6. This system was investigated at only one set of machining conditions (153 rpm and a feed rate of 0.018 in/rev). The length of the cut was 2.4 in.

The data shows that over a relatively large diameter range (5.040 to 3.290 in.) the relationship between temperature and diameter times cut size is linear (Fig. 7).

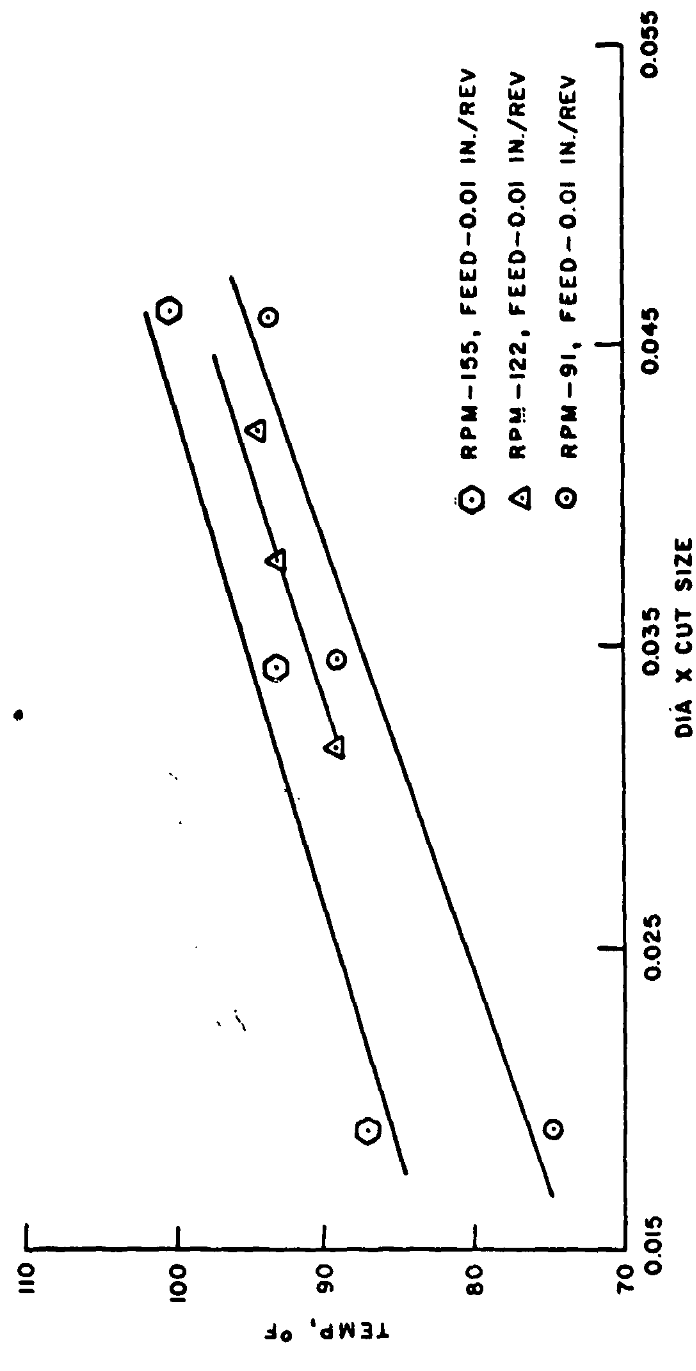

FIG. 6. Temperature versus Diameter Times Cut Size - PL 6503.

TABLE 5. Machining of PL 6503

Run	Diameter, in.	Rpm	Feed, in/rev	Length of cut, in.	Cut size, in.	Diameter times cut, in.	Temp, °F
	0.760	91	0.01	2.4	0.025	0.0190	75
1	0.710	91	0.01	2.4	0.065	0.0462	93
	0.580	91	0.01	2.4	0.060	0.0348	89
	0.760	122	0.01	2.4	0.050	0.0380	93
2	0.660	122	0.01	2.4	0.065	0.0429	94
	0.530	122	0.01	2.4	0.060	0.0318	89
	0.760	153	0.01	2.4	0.025	0.0190	87
3	0.710	153	0.01	2.4	0.065	0.0462	100
	0.580	153	0.01	2.4	0.060	0.0348	93

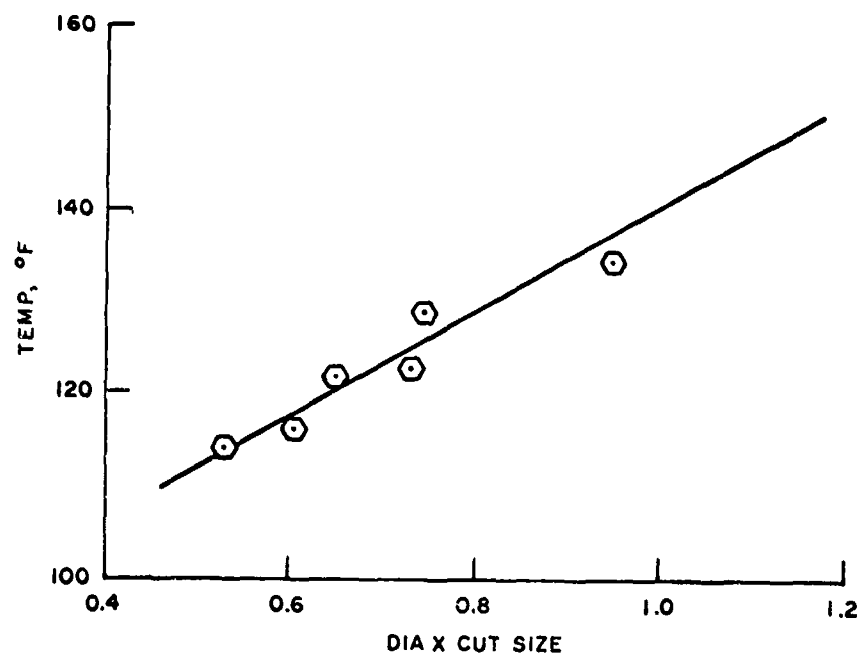

FIG. 7. Temperature versus Diameter Times Cut Size - X-14.

TABLE 6. Machining of X-14

Diam, in.	Rpm	Feed, in/rev	Length of cut, in.	Cut size, in.	Diameter times cut	Temp, °F
5.040	153	0.018	2.4	0.150	0.756	129
4.740	153	0.018	2.4	0.200	0.948	135
4.340	153	0.018	2.4	0.050	0.217	100
4.240	153	0.018	2.4	0.125	0.530	114
3.990	153	0.018	2.4	0.150	0.599	117
3.690	153	0.018	2.4	0.200	0.738	123
3.290	153	0.018	2.4	0.200	0.658	122

E-107 AND C-55 - COMPOSITES

The last propellant systems investigated were E-107 and C-55 composites. E-107, a polyurethane containing (by weight): 23.1% Estane, 0.78% trimethylolpropane, 0.26% 1,4 butanediol, 0.86% triethanolamine, 17.7% Al, and 57.3%, 200 μ, AP. C-55, a carboxy terminated polybutadine containing: 13.07% Butarez CTL-II, 0.43% HX 868, 0.5% iron oxide, 17.0% Al, H-5, and 69.0% AP, trimodal.

E-107 was machined at 153 rpm and a feed rate of 0.018 in/rev; the initial diameter was 8.702 in. The relationship between temperature and diameter times cut size is linear (Fig. 8). Table 7 tabulates the pertinent data for the experimental run.

C-55 was machined at 122, 153, and 202 rpm. The feed rate was held constant at 0.018 in/rev for all three runs; once again the temperature versus diameter times cut size relationship is linear (Fig. 9 and Table 8).

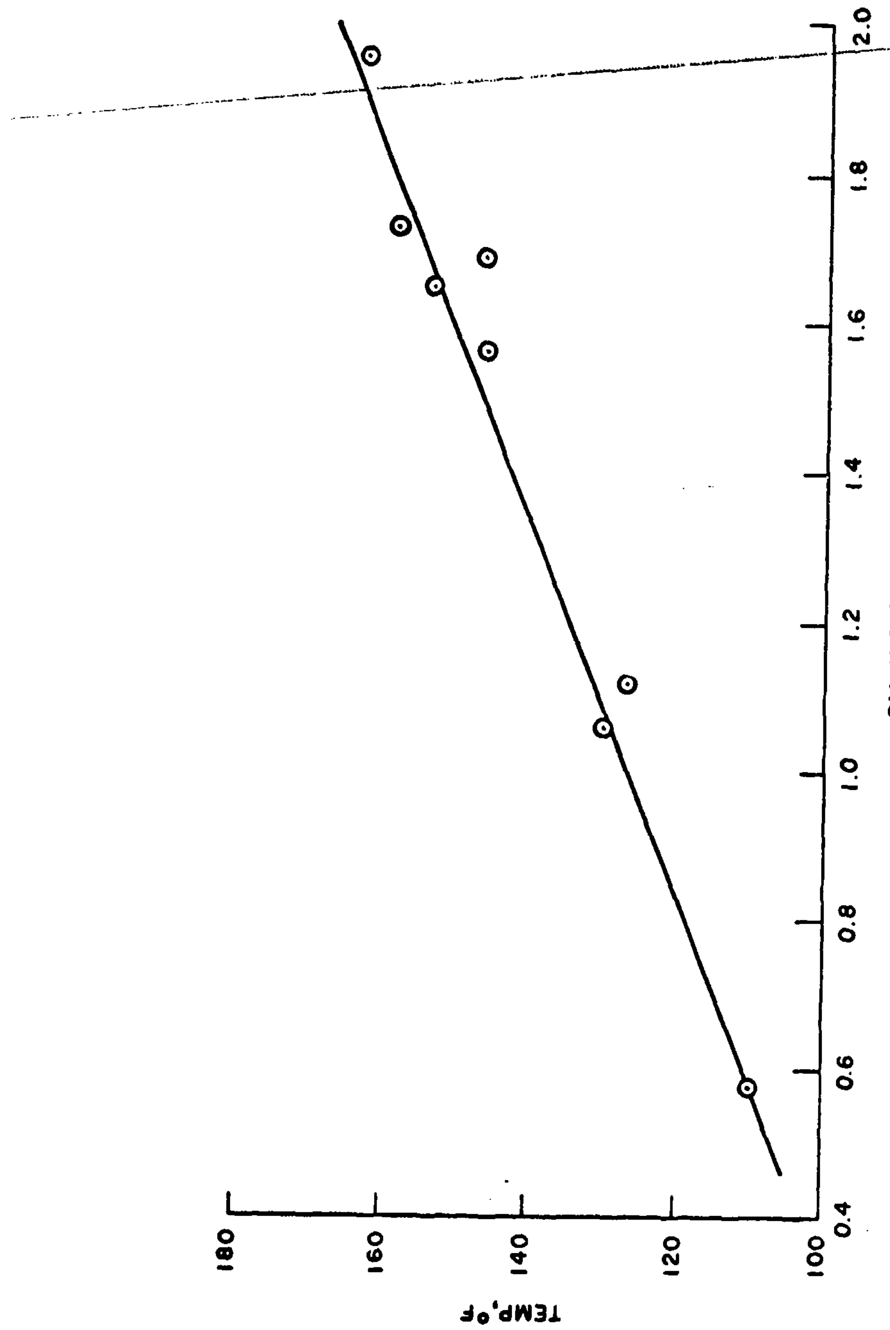

FIG. 8. Temperature versus Diameter Times Cut Size - E-107.

TABLE 7. Machining of E-107

Diam, in.	Rpm,	Feed, in/rev	Length of cut, in.	Cut size, in.	Diameter times cut	Temp, °F
8.702	153	0.018	2.4	0.200	1.740	157
8.302	153	0.018	2.4	0.200	1.660	152
7.902	153	0.018	2.4	0.250	1.976	161
7.402	153	0.018	2.4	0.150	1.110	126
7.102	153	0.018	2.4	0.150	1.065	129
6.802	153	0.018	2.4	0.250	1.701	145
6.302	153	0.018	2.4	0.250	1.576	145
5.802	153	0.018	2.4	0.100	0.580	110

IGNITION STUDIES

Six cylindrical samples, 4.0 in. long and 0.75-in. diameter, were obtained from each of the propellants investigated (PL 6503, PL 6301, RG 6142.2, X-14, E-107, and C-55). The propellants were machined at 296, 361, 401, 573, and 1,000 rpm, with the exception of C-55, which was machined at 573 and 400 rpm. All the cuts were 0.075 in. on the radius and the feed rate was 0.0192 in/rev (Fig. 10 and Table 9).

E-107 - COMPOSITE

During machining at 296 and 316 rpm the propellant sample bowed excessively; the propellant pulled out of the chuck after 2 in. had been machined. Temperatures of 105 and 107°F were obtained. No bowing occurred during machining at 401 and 573 rpm; the temperatures reached were 100 and 105°F. Bowing occurred at 1,000 rpm, but the sample did not pull out of the chuck. The temperature reached was 112°F.

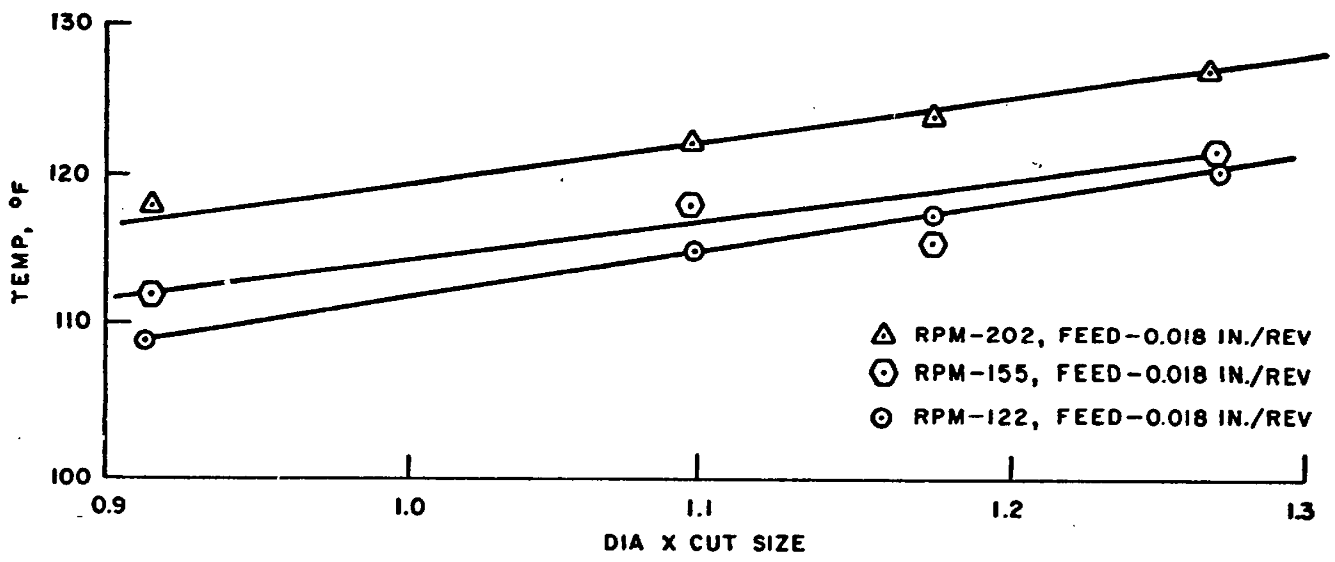

FIG. 9. Temperature versus Diameter Times Cut Size - C-55.

TABLE 8. Machining of C-55 Composite

Diameter, in.	Cut size, in.	Length of cut, in.	Feed, in/rev	Diameter times cut, in.	Rpm	Temp, °F	Rpm	Temp, °F	Rpm	Temp, °F
5.875	0.200	2.4	0.018	1.175	122	117	155	116	202	124
5.475	0.200	2.4	0.018	1.095	122	115	155	118	202	122
5.075	0.250	2.4	0.018	1.268	122	120	155	121	202	127
4.575	0.200	2.4	0.018	0.915	122	109	155	112	202	118

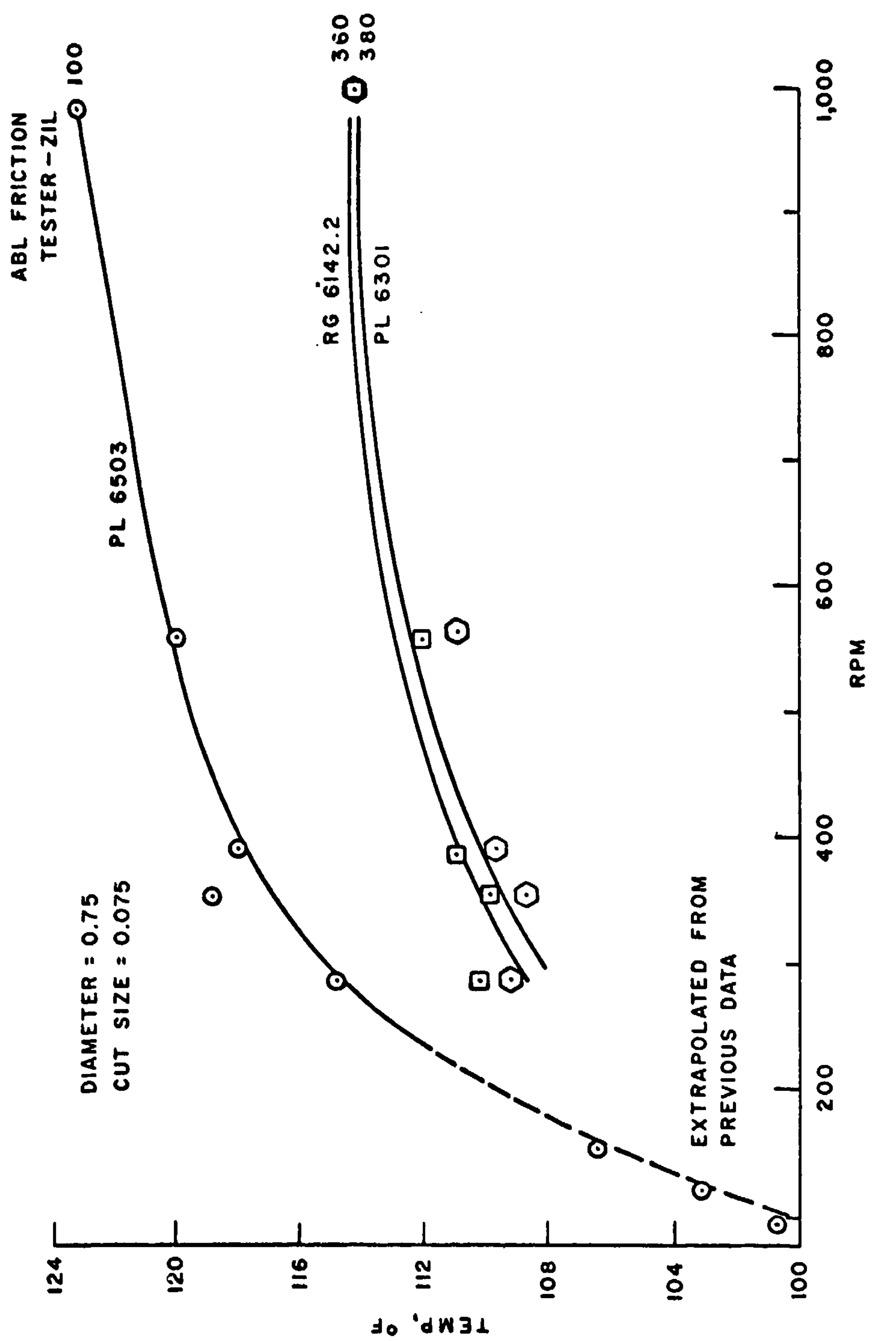

FIG. 10. Temperature versus Rpm.

TABLE 9. Machining of Various Propellant Systems

Propellant	Shore hardness	Rpm	Temp, °F	Comments
E-107	80	296	105	Propellant bowed and pulled out of chuck after 2 in. was machined.
E-107	80	361	107	Propellant bowed and pulled out of chuck after 2 in. was machined.
E-107	80	401	100	Normal machining.
E-107	80	573	105	Normal machining.
E-107	80	1,000	112	Bowing of the propellant occurred.
C-55	60	573	...	Broke almost on contact with tool bit - 1/2 in. of propellant machined.
C-55	60	401	...	Broke almost on contact with tool bit - 1/2 in. of propellant machined.
X-14	95	296	100	Normal machining - machined propellant came off in chips.
X-14	95	361	102	Normal machining - machined propellant came off in chips.
X-14	95	401	102	Normal machining - machined propellant came off in chips.
X-14	95	573	102	Normal machining - machined propellant came off in chips.
X-14	95	1,000	101	Normal machining - machined propellant came off in chips.
RG 6142.2	90	296	110	Normal machining.
RG 6142.2	90	361	110	Normal machining.
RG 6142.2	90	401	111	Normal machining.
RG 6142.2	90	573	112	Normal machining.
RG 6142.2	90	1,000	114	Normal machining.

TABLE 9. (Cont'd)

Propellant	Shore hardness	Rpm	Temp, °F	Comments
PL 6301	95	296	109	Normal machining.
PL 6301	95	361	109	Normal machining.
PL 6301	95	401	110	Normal machining.
PL 6301	95	573	111	Normal machining.
PL 6301	95	1,000	114	Normal machining.
PL 6503	95	296	115	Normal machining.
PL 6503	95	361	119	Normal machining.
PL 6503	95	401	118	Normal machining.
PL 6503	95	573	120	Normal machining.
PL 6503	95	1,000	123	Normal machining.

NOTE: Diameter - 0.75 in.
Cut size - 0.075 in.

C-55 - COMPOSITE

In view of the fact that relatively low temperatures were obtained in the machining of E-107, it was decided to start the machining of C-55 at 573 rpm. However, the propellant snapped almost on contact with the tool bit; the same results were obtained at 400 rpm. There was no sparking or any anomaly during the breaking of the propellant samples. The C-55 has a Shore hardness of 60 which is low, compared to the other systems investigated and accounts for the breaking of the sample.

X-14 - DOUBLE BASE

X-14, a hard propellant with a Shore hardness of 95, was the only double-base system studied. All five samples were machined without difficulty; the maximum temperatures reached was 102°F. This propellant machined differently than the others in regard to the removal of machined propellant. The cut propellant came off in small chips compared to the other systems in which cut propellant came off in strands. This results in a quick removal of any heat buildup in the system and consequently the low temperatures.

RG 6142.2 - FLUOROCARBON

RG 6142.2, with a Shore hardness of 90, was the first fluorocarbon machined in this series of experiments. No difficulties in machining were encountered; a maximum temperature of 114°F was obtained at 1,000 rpm.

PL 6301 - FLUOROCARBON

PL 6301, a fluorocarbon propellant with a Shore hardness of 95, is approximately as sensitive as the RG 6142.2 based on the ABL friction test. The machining was done with no difficulty and the temperatures were within 1°F of temperatures obtained with RG 6142.2. A maximum temperature of 114°F was obtained at 1,000 rpm.

PL 6503 - FLUOROCARBON

PL 6503 is an extremely sensitive fluorocarbon system which had ignited on the lathe during a normal machining operation. However, at 1,000 rpm, no ignition or extreme temperature buildup occurred. The maximum temperature was 123°F at 1,000 rpm.

ORDER OF SENSITIVITIES

The results of the ABL friction test were:

Propellant	Force, lb (Zil)
PL 6503	100
X-14	160
C-55	300
RG 6142.2	360
PL 6301	380
E-107	700

Temperature comparisons cannot be made at all rpm's due to the fact that bowing of E-107 occurred at 296, 361, and 1,000 rpm. Also, X-14 which has different machining characteristics (the machined propellant comes off in chips rather than strands) should not be compared to the other propellants.

Therefore, only the results obtained at 401 and 573 rpm can be compared.

Propellant	ABL results	Temp, 401 rpm	Temp, 573 rpm
PL 6503	100	118	121
RG 6142.2	360	111	112
PL 6301	380	110	111
E-107	700	100	105

The temperatures are in the same order as the sensitivities; the most sensitive propellant having the highest temperature and the least sensitive having the lowest for a given set of machining conditions.

TEMPERATURE-RPM RELATIONSHIP

The temperature-rpm relationship was previously thought to be linear; however, the temperature begins to level off at higher rpm's. It is felt that this is due to two phenomena; first, at the higher rpm, convection which is related to the movement of air around the propellant as it is being machined, removes part of the heat as it is being built up; secondly, the propellant strands which actually ~~contain most~~ of the heat are being removed at a rapid rate and consequently transfer very little heat. These two effects tend to lower temperatures and it appears that the temperatures begin to approach a maximum regardless of the rpm.

CONCLUSIONS

There was no ignition or extreme temperature buildup of the fluorocarbon, composite, or double-base systems at high rpm's (1,000 rpm, 0.0192 in/rev feed rate, and 0.075 in. cut size on the radius). The temperature-rpm relationship appears to approach a maximum regardless of rpm. Both of these phenomena are attributed to: (a) relatively low diameter times cut size number of 0.05625 in. (0.75 in. diameter times 0.075 in. cut size); (b) the removal of heat by convection; and (c) the removal of heat by the machined propellant leaving the system at a rapid rate.

The limited data obtained from this machining study indicates that the ABL friction tester is able to qualitatively predict sensitivities of propellants in regard to machining.

The temperature rise experienced by the grain is an exponential function of the rpm being linear in the range of 90 to 200 rpm and tendency to level off up to 1,000 rpm. The temperature rise is also a linear function of the diameter times cut size and this can be used to predict temperature.

Freon 113 sprayed as a mist on the propellant operated most effectively of the coolants evaluated, in lowering the temperature as the grain was being machined.

Although the work indicates that some propellant machining may be done without coolant, it is not recommended to do so. It is felt that in the event operating conditions are not optimum (tool bit not being sharp, foreign particles in the grain, etc.) the coolant will provide a margin of safety.

Dale: I would estimate that your ft. per min. on the cutting of these propellants was somewhere around between 200 and 400 ft. per min., is this correct?

Landau: I intentionally did not use ft. per min. or calculate in ft. per min. I wanted a number which I felt had more value and when running thru this experiment, this diameter times cut number at a specific rpm had more meaning to me.

Dale: What I was getting at was did you either get some data or would you estimate at what factor times the number that you have for the diameter times cut if you would get ignition. In other words, what kind of a safety factor would you have?

Landau: I don't know, as I said, we machined up to 1,000 rpms. We did take a small cut, we did not get ignition. Also we machined at much more severe conditions than we use in routine operations and we had gotten ignition during routine operations in most of the cases the cause has been unknown.

Dale: In other words, there may have been another mechanism where you caught some chips between your tool and your propellant.

Landau: Very conceivable.

Buschmann, NPP: How did you measure these temperatures and were these in Fahrenheit?

Landau: Yes, the temperatures were in Fahrenheit. They were measured via a thermocouple imbedded probably around 1/16th below the cutting edge of the tool bit. I realize there is a little thermal lag and some heat absorption by the tool bit but the trend and the linear relationships developed do hold.

Oeinck: On your cutting tool, specifically, what type of tool did you use?

Landau: A standard tool bit. It was not designed specifically for machining, its a commercial item.

Oeinck: Its, in other words, a flutted rotary cutter?

Landau: No flutes.

LEGAL ASPECTS OF AN EXPLOSION

Bruce M. Docherty
Assistant General Counsel
Department of the Army

The legal consequences of an explosion may be affected by state law or municipal ordinance as well as by federal statutes and regulations. We can't, of course, go into all the ramifications in 45 minutes. Naturally you will want to consult your own counsel on specific problems.

I do not pretend to technical expertise in the various scientific fields represented here. Close attention to the fine technical papers at these seminars has not always given me 100 percent comprehension. Let me put it this way. I really don't know what's in that stuff you're mixing but I do have some idea of what will happen if it blows up.

The courts tend to hold landowners absolutely liable when the use of their property is unusually hazardous. Take the tiger for example. We see quite a bit of the tiger today. He smiles on us as we drive along the highway. Perhaps he has something to tell us.

In the year 1875 an English court suggested that if a man kept a tiger securely chained, and lightning broke the chain, and the tiger escaped and did mischief, the man who kept the tiger would be liable.[1]

More recently, in 1957, another English court expressed the view that the liability imposed upon the owner of a tiger may be quite unlimited. The court said:

> If a person wakes up in the middle of the night and finds an escaping tiger on top of his bed and suffers a heart attack, it would be nothing to the point that the intentions of the tiger were quite amiable.[2]

There may be absolute liability then, for the escape of a chained tiger, or for an explosion in a plant.

Ordinarily a person involved in an accident is not legally responsible unless he was negligent, that is, unless he failed to use reasonable care for the safety of others. Many courts, however, hold business or industrial concerns absolutely liable for damage caused by extra hazardous activities. This is particularly true of concerns engaged in the manufacture, handling or storage of explosives.

When there is absolute liability it makes no difference how good the plant safety regulations may be or how carefully they have been

followed. If there is an explosion, and someone is injured, the company will be liable.

The reason for this rule is the notion that an extra-hazardous or ultra-hazardous activity should pay its own way. Both the owner of the plant and the person injured may be entirely blameless. But it seems to the court that the businessman who chooses to carry on a dangerous activity should pay for the damage which results. Presumably he can treat this liability as a business expense to be reflected in the price of his product. Perhaps the loss will be spread over a larger segment of the community through some form of liability insurance.

Even courts which follow this rule do not hold a business concern absolutely liable for every injury resulting from an explosion. The injury must come from the type of risk which makes the industrial activity dangerous to the rest of the community.

For example, the owner of a mink ranch complained that nearby blasting frightened and excited the mink. Mink kittens were stunted in growth and the quality of the pelts deteriorated.

The court refused to apply the rule of absolute liability. Blasting was ultra-hazardous because of the danger of physical damage from the force of an explosion. The mink's difficulties were purely psycological, resulting from a peculiarity of the mink disposition.[3]

Of course the explosion must be the cause of the injury - whether liability depends on defendant's carelessness or is imposed regardless of fault. This is the doctrine of proximate cause. Defendant will not be liable if the court regards plaintiff's injury as remote or not reasonably foreseeable.

It is not always easy, however, to tell what is reasonably foreseeable. An early case on explosives may help to illustrate.

On October 28, 1770, a boy named Shepherd attended a fair at Milborne Port, Somerset County, England. Just how it compared with the New York World's Fair I do not know. Apparently young Shepherd found it dull.

At any rate he tossed a lighted squib - or firecracker - into a crowded market place, perhaps hoping to liven things up. Things did liven up. This was a large and formidable looking squib - a firecracker consisting of gunpowder and other combustible materials. It landed on a vendor's stand and lay there among some cakes and pies, smoldering. James Willis, who was at the stand, grabbed the squib and threw it across the market place. It fell on the stand of James Ryall, also a seller of cakes and pies. Ryall threw it to still another part of the market place. This time it hit a boy named Scott, exploding and

injuring him. Scott sued Shepherd, who had first thrown the lighted squib.

The defendant argued that he had not thrown the squib anywhere near the plaintiff. Since he could not have foreseen what actually happened, he should not be held liable.

The court felt, however, that anyone throwing an explosive into a crowd should expect that someone might be injured. The instinctive acts of Willis and Ryall did not break the chain of causation.

Plaintiff was awarded damages of 100 pounds, quite a goodly sum in those days.[4]

Even where the courts do not impose absolute liability it is not easy for a business concern to escape the legal consequences of an explosion. Anyone dealing with explosives must conform to a very high standard of care.

For example, the handling and transportation of explosives have been the subject of federal, state and municipal regulation. The Interstate Commerce Commission regulates the transportation of explosives in interstate commerce.[5] Violation of any of these regulations - federal, state or local - may mean legal liability for damage caused by an explosion. Such violation, without more, may be regarded as proof of negligence, irrespective of possible criminal liability.

Now suppose that someone is injured in an explosion and wants to sue the Federal Government. How does this differ from a suit against a contractor?

The Government cannot be sued without its consent. This is known as sovereign immunity. Its origin lies in the ancient notion that the King can do no wrong. If a person suffered injury because of the negligence of an employee of some Federal agency, he could not sue the Government. His remedy, sometimes quite inadequate, was to seek relief through a private bill in Congress.

This was before 1946. In 1946 Congress enacted the Federal Tort Claims Act.[6] By that Act the Government consented to be sued in this kind of situation. Suits may be brought in the Federal District Courts. The Government becomes liable in accordance with the law of the particular state where the accident or injury occurred. A tort by the way is simply a private or noncriminal wrong which does not arise out of a contract. Automobile accidents are a common example.

In 1947, the year after the Tort Claims Act became law, two vessels being loaded with fertilizer exploded at Texas City, Texas. More than 500 persons were killed and 3,000 injured.

Fire broke out in the fertilizer which had an ammonium nitrate base. The explosions resulted. The fertilizer had been manufactured as part of a federal program and under the general supervision of a Government contracting officer. Contracts had been placed with private firms to operate Army plants in producing the fertilizer.

Suits were brought under the Tort Claims Act in the amount of 200 million dollars. A test case came before the Supreme Court in 1953.

The Tort Claims Act exempts the Government from liability for errors which may be committed by its employees in exercising discretionary functions. The District Court had found negligence in Government decisions as to the manufacture, bagging and shipment of the fertilizer. The Supreme Court said these decisions were at a planning rather than an operational level. Thus they were made in the exercise of a discretionary function of Government.

As far as the Government's liability was concerned, it made no difference whether these decisions were right or wrong. The Government had not consented to be sued for errors or carelessness in making that kind of a decision. The Supreme Court held that the Government was no not liable.[7]

The Supreme Court said further that the doctrine of absolute liability did not apply to the Federal Government. Someone must be negligent before the Government could be held liable. So the United States would not be legally responsible for an injury merely because it carried on an extra-hazardous activity.

Three of the Justices dissented. They thought that the Government should be held liable for the consequences of the explosions. The dissenting opinion contains the following comment on the scope of the Tort Claims Act:

> Surely a statute so long debated was meant to embrace more than traffic accidents. If not, the ancient and discredited doctrine that "The King can do no wrong" has not been uprooted; it has merely been amended to read, "The King can do only little wrongs."[8]

The Texas City claimants were not left without redress. Subsequent to the Supreme Court's decision Congress, by special act, provided for payment of their losses up to $25,000 for each claim.[9]

Two years after the Texas City decision, the Supreme Court indicated that once a federal agency undertakes a project, the planning stage is over. Decisions then become operational and the Government is liable for negligence.[10] This greatly broadens Government liability. For example, decisions as to the bagging and shipment of fertilizer would probably be operational under this rule.

What about absolute liability? Suppose the Government carries on an extra-hazardous activity today. Is it absolutely liable for injuries to others? In 1953, you remember, the Supreme Court answered this question in the negative. Later federal cases have raised a serious doubt as to whether this limitation still applies to cases under the Tort Claims Act.

Let me give you one example. Shortly after the Texas City decision, the Federal Court of Appeals for the Fourth Circuit held the Government absolutely liable for injuries caused by an explosion. Two Government airplanes fell and exploded in South Carolina, causing personal injuries and property damage.

The planes were on Government business, and were being operated by Government employees. A South Carolina statute made the owner of an airplane absolutely liable for injuries caused either by its flight or by an object falling from it.

The Court of Appeals applied the South Carolina statute and held the Government absolutely liable for the damage caused by the explosions. There was no need for the plaintiffs to show that the Government employees had been careless or had made some mistake. In other words, no showing of negligence was necessary. All the plaintiffs had to prove was that they had suffered loss or injury as a result of the Government's operation of an airplane. The exercise of due care by Government personnel was no defense at all. The Supreme Court was asked to review this decision but declined to do so.[11]

The extent of the Government's liability under the Tort Claims Act is not entirely clear at the present time. There is no doubt that it is much broader than was indicated by the Texas City decision. I think that as a practical matter the Government's liability for an explosion is not much different from that of private industry.

Suppose we look at two recent cases where the Government was sued under the Tort Claims Act.

In the first case plaintiff was employed by a private concern which was manufacturing detonators and other explosives under an Army contract. The work was being done at a Government owned contractor operated plant. As part of her duties plaintiff fed component parts of the detonators into an automatic loader. After completion of the loading operation she inspected the detonators. She then sorted them by hand, placing them in cardboard set-up boxes or trays. The detonators which passed inspection were put in one tray; the rejects in another.

During the sorting and traying operation there was an explosion. Plaintiff was severely injured and sued the United States.

The District Court found that plant safety was a joint responsibility of the Government and the contractor. Acts of Government personnel in carrying out this responsibility were on the operational level. The Government, therefore, was not administering a discretionary function for which it could escape liability under the Tort Claims Act.

The Court said:

> . . . the Government, by its action in placing on the job seventy-two safety inspectors throughout the whole process of manufacturing these detonators, had assumed the mandatory duty to insure the safe operation of the plant, and a duty upon which this plaintiff could reasonably rely.
>
> • • •
>
> . . . the Government owned the plant machinery and equipment and was jointly responsible for the safety of their operation. Furthermore... the (Government) owed the Plaintiff a proportionally higher degree of care than the ordinary affairs of life would dictate due to the extremely dangerous nature of the work being performed. . . .

Although the work was extra-hazardous the Court did not adopt the rule of absolute liability. A finding of negligence was necessary, therefore, before the plaintiff could recover. There were some difficulties involved in making such a finding. It was almost impossible to determine the exact cause of the accident. No one could point to any specific act of negligence on the part of Government personnel which actually caused the explosion.

The District Court did find that the Government had been negligent. The Judge commented generally on the evidence as follows:

> We are confronted here with the undeniable fact of the explosion, and nowhere has the (Government) advanced a satisfactory theory as to any fault of the Plaintiff's which would absolve... (the Government) of liability.

The Judge then observed that the detonator would explode upon contact with a weight of one ounce traveling a distance of five inches. Since the product was so likely to explode he thought it unreasonable to require a showing of just how the detonation occurred.

After speculating on several possibilities the Judge accepted plaintiff's theory. This was that the blast occurred when foreign metal particles from a cardboard traying box came into contact with the sensitive end of a detonator. His conclusion followed:

The Court therefore finds that the Defendant, United States, was negligent in furnishing cardboard trays containing foreign metal particles and that this negligence was the proximate cause of the injuries and damages sustained by Plaintiff.

The Court awarded plaintiff damages of approximately $93,000.[12] The Government did not appeal.

The Judge indicated that if the Government's negligence could not have been proved to his satisfaction he would have found for the plaintiff anyway under the rule of res ipsa loquitur. This phrase means simply "the thing speaks for itself." It is often used by the courts to permit an inference or presumption of negligence when plaintiff cannot show how an accident occurred.

In this case the Judge viewed the matter about as follows. The plaintiff was injured while working with Government equipment and material. Presumably there would not have been an explosion unless the equipment or material furnished to her was defective. If plaintiff cannot determine the cause of the accident it is up to the Government to show it was not to blame.

Of course the Government would not be liable if the plaintiff's own negligence was responsible for the accident. The Government theorized that the plaintiff might have caused the explosion by striking two of the detonators together. As to this argument the Judge merely observed that the Government should have devised a procedure to prevent this - some arrangement whereby the operator could use only one hand at a time.

I think this case illustrates that when a dangerous instrumentality explodes it is very difficult indeed for the owner of that instrumentality to escape liability. This is true either of the Government or of private industry.

Another point may be of interest. Plaintiff had already received workmen's compensation payments from an insurance company. The Court's opinion provided for reimbursement of the insurance company from the amount which plaintiff recovered from the Government.

All states have Workmen's Compensation Acts although they differ considerably in detail. They are based on the theory that the employer should bear the burden of industrial accidents. Compensation to an employee for injuries received in the course of his employment is regarded as a cost of modern business, to be passed on to the consumer.

A system of liability insurance is set up to cover payments to injured employees. In some cases a large employer may become a self insurer.

Under Workmen's Compensation Acts an injured employee will usually receive compensation regardless of the cause of the accident. It makes no difference if the employee was careless and his employer entirely blameless. If the employee is killed in an explosion his family or his personal representative - executor or administrator - has a similar right to compensation.

Workmen's compensation payments are a substitute for the legal rights a worker would otherwise have against his employer. The worker gives up his right to sue in return for certainty of compensation. In some states the employees of a subcontractor are regarded as employees of the principal contractor for the purposes of workmen's compensation.

The maximum amount of compensation varies from state to state. It might be $15,000 or $25,000. Naturally the amount payable varies with the seriousness and extent of the injury.

When there is an explosion in a contractor's plant the contractor will not usually be sued by his injured employees. Their claims will be taken care of under workmen's compensation.

There is a similar situation as to Government personnel, civilian or military. Federal law provides compensation for Government personnel injured while on duty. This is a substitute for rights they might otherwise have to sue the Government.[13]

Suppose we turn now to the second of the two recent cases I mentioned. Here again a contractor's employee sued the Government under the Federal Tort Claims Act. This time, however, the explosion occurred at a privately owned privately operated plant.

A company was performing research and development work under an Air Force contract. There was an explosion and three employees of the company were killed. The widow of one of these employees sued the Government.[14]

The United States District Court gave judgment for the plaintiff in the sum of $100,000.

Apparently the widow had already received death benefits under the state Workmen's Compensation Act. It may be noted that the maximum workmen's compensation in this case would probably amount to less than $15,000. This is in contrast to the $100,000 awarded by the Federal District Court as the result of the same accident.

The company was an independent contractor under a cost-plus-fixed-fee type of contract. The accident occurred while the Contractor was engaged in the production of solid fuel propellant for experimental rockets.

The propellant was manufactured by placing explosive casting powder, and a solvent containing nitroglycerin, in a mold. The molds were then put through a curing process.

Upon completion of this process the Contractor's employees removed the molds from the "cure" building and placed them on a trailer standing at the door. The transfer from the building to the trailer was accomplished by means of an overhead air hoist and crane.

The molds, when loaded, weighed 340 pounds and contained about 120 pounds of propellant. On the day of the accident eight molds were being removed from the "cure" house. Three were placed in the trailer. A fourth mold was being taken to the trailer by the air hoist. At approximately this point the explosion occurred.

The Judge found that the molds were Government property. He found also that they were inherently dangerous since their narrow base and high center of gravity made them unstable - easy to tip over to rock.

At the trial several possible explanations were given as to the cause of the explosion. For example, a mold inside the building might have been knocked over so that it hit the floor. Or the explosion might have occurred on the trailer if a mold had fallen off or been tipped over.

Contractor's safety regulations required that the molds be moved only by means of the hoist. There was evidence, however, that despite these instructions, Contractor's employees used the hoist only to place the molds on the rear of the trailer. After disconnecting the hoist they would then move the molds to the front of the trailer by hand. The following colloquy is taken from the testimony of one of Contractor's employees who had gone to another building just prior to the explosion. Government counsel was cross-examining the witness.

Q. You set (the molds) down on the trailer and then you moved them to the front of the trailer? A. Yes sir.

Q. How far was it from the point where you set them down to the front of the trailer? A. About three feet.

Q. About three feet. You moved them three feet after you set them down. And how did you move them? A. We tipped them back and walked them.

The Court: You did what?

The Witness: Tipped them back toward our body and walked them.

The Court: These things?

The Witness: Yes sir.

The Court: Full of nitroglycerin?

The Witness: Yes sir.

After hearing all the evidence the District Court found that the exact cause of the explosion was unknown, but that the initiating detonation had occurred inside the building. The Court thought it probable either that one of the molds had been pushed over or that some object had impacted with a mold with sufficient force to detonate it. This was only conjecture, however.

The Court then went on to find that the Government had been negligent, and that its negligence was a concurring proximate cause of the death of Contractor's employee. The Court also found that there had been no contributory negligence on the part of the deceased employee which would prevent his widow from recovering damages from the Government.

Briefly summarized, this was the Court's position. Under the contract terms the Government could have prescribed additional safety measures. It failed to do so. The molds were Government property. They were unsafe, but the situation was not corrected although a number of Government personnel were on duty at the plant. If work is inherently dangerous the Government cannot escape responsibility by having it performed by an independent contractor, unless all proper precautions are taken.

The Government appealed. The Circuit Court of Appeals reversed the lower court's decision and held that the United States was not liable.

The Court of Appeals relied on the general rule that an employer is not liable for the torts of an independent contractor. Here the contractor had direct control and supervision over its own employees working in its own plant and had primary responsibility for their safety. As to the molds, they were technically Government property but the Government had exercised no control over them.

As was indicated in the opinion of the lower court, there is a rule to the effect that if work is inherently dangerous an employer may be liable for injury to others even though the actual work is done by an independent contractor. The Court of Appeals felt, however, that this rule should not be applied to suits brought by the employees of an independent contractor as was the case here; in any event the Government is liable for negligence only if it is the negligence of one of its own employees. The Court of Appeals said that an independent contractor is not an employee of the Government within the meaning of the Tort Claims Act.

Now for a look at the future. What would happen if a really catastrophic explosion occurred in some Government program? What procedures are available for payment of compensation?

The military departments, NASA and AEC can pay claims up to $5,000 for personal injuries, death or property damage.[15] If the accident occurs outside the United States, the military departments can pay claims up to $15,000.[16]

If an agency considers that claimant should receive an amount beyond the limits for administrative settlement it may report the excess to Congress for consideration. If the claimant does not receive satisfaction through the foregoing procedures he may sue the Government under the Federal Tort Claims Act. This Act does not, however, apply to claims arising in a foreign country.[17]

The victims of a catastrophic accident might bring suit against a contractor or subcontractor. Such a lawsuit could have very serious financial consequences.

The doctrine of product liability has been greatly expanded in recent years. Under this doctrine a contractor might be liable to persons injured by a failure or defect in his product, even after delivery of the product to the Government. Liability would be based on the idea that negligence in the manufacture of a dangerous product can be expected to result in injury to those who may come in contact with it.[18]

We have already seen that those carrying on extra-hazardous work may be absolutely liable for accidents in the course of that work. Also that such liability cannot always be avoided by turning the work over to an independent contractor.[19]

Business concerns might, therefore, be exposed to extremely heavy financial liability as the result of an explosion. In the absence of some applicable contract provision their chances of being indemnified by the Government are quite doubtful.

The law in this area is by no means clear. There are courts which say, however, that when one person is liable for an injury to another he may not obtain contribution or indemnity from a third person jointly responsible for the injury.[20]

In such states the whole financial burden of plaintiff's injury might fall on the person plaintiff chose to sue - whether contractor or Government.

This assumes of course that there is no indemnification agreement in the particular case.

Then, what about indemnification of contractors by the Government? The military departments can indemnify research and development contractors without dollar limitation against unusually hazardous risks.[21] AEC can indemnify against liability up to an aggregate of 500 million dollars for any one nuclear incident.[22] Under either authority contractors would be indemnified only as to amounts in excess of private insurance coverage.

There is also general authority under Public Law 85-804 to indemnify contractors against unusually hazardous risks. This authority is available to a number of agencies, including DoD, NASA and AEC. It may be exercised, however, only "within the limits of the amounts appropriate . . . therefor." This limitation severely restricts the amount of indemnification, in some cases, perhaps, to little more than the amount obligated under the contract.[23]

Under existing law neither the public nor Government contractors are adequately protected from the possible results of a major catastrophe. It is possible to envision a situation where claims might far exceed the 200 million dollar figure of the Texas City Disaster. It is doubtful if private insurance coverage obtainable against such a risk would exceed 30 million dollars.

This subject has been treated in a recent Columbia University Study sponsored by the National Security Industrial Association[24] and the need for more comprehensive statutory coverage has been carefully considered by DoD in collaboration with other agencies. The problem has been discussed informally with representatives of industry.

I think it would be appropriate to conclude these remarks with a brief summary of two proposals now under consideration. They have not yet been submitted to Congress.

The law now provides for federal action in natural catastrophes such as floods, earthquakes or droughts.[25] One proposal contemplates similar federal action in the event of a catastrophic accident. The President would be authorized to provide for the restoration of essential public services.

The Government would also pay compensation, up to $25,000 per person, for damages resulting from the accident. This administrative payment would be made whether or not the Government was legally responsible for the accident. Despite this payment, claimants could pursue their usual legal remedies against the Government, or its contractors or subcontractors. If, however, the claimant later recovered damages at law, the Government would be credited with or reimbursed for the amount of its administrative payment.

Public Law 85-804 would be broadened to permit indemnification of contractors and subcontractors up to an aggregate of 500 million dollars for any one incident. Indemnification would be for amounts in excess of coverage by private insurers. Liability of all contractors, subcontractors and suppliers indemnified would be limited to 500 million dollars.

An alternate proposal would use a different approach when a catastrophic accident occurs in a Government program. This plan would become operative only when an accident involved claims of more than 10 million dollars.

In such a case the Government would become solely responsible for all losses from the accident. The Government would pay emergency interim compensation up to $25,000 per person. Claimants could also sue the Government under the Federal Tort Claims Act. They would have to prove only that they suffered loss as a result of the accident. No showing of Government fault or negligence would be required. Any award under the Tort Claims Act would be reduced by the amount of the emergency payment.

Claimants would have no right of action against contractors or subcontractors. Their only remedy would be against the Government.

If the accident occurred through a prime contractor's negligence, the Government could recover from that contractor the amounts that the Government had paid to injured claimants. This right of recourse would not exceed an amount which would be specified in the contract. It would never exceed 10 million dollars as to any one contractor. Presumably no contractor would be subjected to this kind of liability beyond amounts for which private insurance is normally available at reasonable rates.

As you can see, these proposals are quite different. The first relies to a large extent on existing legal machinery and stresses indemnification of contractors and subcontractors. Under the second plan the Government would assume full legal responsibility to those injured in the accident. Both plans contemplate the supplemental use of private liability insurance. Either plan would seem to provide quite comprehensive protection both for the public and for Government contractors and subcontractors in the event of a catastrophic accident.

DoD and NASA have indicated a preference for the first of these two proposals, that is, the one emphasizing indemnification of contractors rather than assumption of sole liability by the Government. The first proposal utilizes existing procedures to the maximum extent. It clarifies these procedures when necessary but does not attempt to carve out new areas of the law.

This first proposal has some disadvantages. For instance, Public Law 85-804 is intended to be used only during emergencies and in extraordinary circumstances. Nevertheless DoD has used the Public Law 85-804 authority ever since the Korean War. The use of this authority, however, requires a finding that it will facilitate the national defense. Perhaps this could be changed to facilitation of the public interest so that agencies with non-defense interests could use the authority.

The essential thing is to protect the public and to clarify and make adequate the protection now available to contractors and subcontractors. These are the objectives that the Government is seeking to accomplish in the field of indemnification.

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FOOTNOTES

1 Nichols v. Marsland, L.R. 10 Ex. 255, 260 (1875)

2 Behrens v. Betram Mills Circus, Ltd., (1957) 2 Q.B. 1, 17, 18

3 Gronn v. Rogers Construction Inc., 221 Or. 226, 350 P. 2d 1086 (1960)

4 Scott v. Shepherd, 3 Wils. K.B. 403, 95 Eng. Rep. 1124 (1773)

5 18 U.S.C. 831-837; 49 U.S.C. 303, 304, 322; 49 C.F.R. Parts 71-78, 197

6 Act of August 2, 1946, 60 Stat. 812, 842-847, now codified in 28 U.S.C.

7 Dalehite v. United States, 346 U.S. 15 (1953)

8 346 U.S. 15 at 60

9 Act of August 12, 1955, ch. 864, 69 Stat. 707

10 See Indian Towing Co. v. United States, 350 U.S. 61 (1955)

11 United States v. Praylou, 208 F. 2d 291 (4th Cir. 1953), cert. denied, 347 U.S. 934 (1954)

12 Martin v. United States, Civil Action 794, E.D. Tex., August 7, 1964

13 See Feres v. United States, 340 U.S. 135 (1950); 5 U.S.C. 757(b) (1964)

14 Page v. United States, Civil No. C-82-63, D. Utah, March 23, 1964; rev'd No. 7880 - May 1965 Term (10th Cir.) August 18, 1965

15 10 U.S.C. 2733; 42 U.S.C. 2473(b)(13); 42 U.S.C. 2207

16 10 U.S.C. 2734

17 28 U.S.C. 2680(k)

18 See 80 A.L.R.2d488; 74 A.L.R.2d 1111

19 See Prosser on Torts (2d ed. 1955) 357, 360; Restatement, Torts § 427

20 See United Air Lines v. Weiner, 335 F. 2d 379 (9th Cir. 1964); Hart v. Simons, 223 F. Supp. 109 (1963); Prosser on Torts (2d ed. 1955) 246-251

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[21] 10 U.S.C. 2354

[22] 71 Stat. 576, 42 U.S.C. 2210

[23] 72 Stat. 972, 50 U.S.C. 1431-1435; Exec. Order No. 10789, 23 Fed. Reg. 8897 (1958) as amended by Exec. Order No. 11051, dated Sept. 27, 1962; Rev. Stat. 3679, 31 U.S.C. 665

[24] Catastrophic Accidents in Government Programs, NSIA 1963

[25] Federal Disaster Act, 42 U.S.C. 1855

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Weiss, Rocketdyne: In the event there is a suit brought against a contractor and negligence was shown, is the contractor open for criminal prosecution in any way?

Docherty: I think the only answer I could give you is that he might be if he had violated some criminal statute, but not merely because of negligence. Negligence is a non-criminal thing; you can be negligent in an automobile accident and there would be no criminal liability. Of course you can also be criminally liable in an automobile accident. If you hit someone accidentally but were a little careless, there's nothing criminal about that; its just that you might be responsible for the injury and you might have to make the person whole. However, if you deliberately ran over him there would be criminal liability.

Weiss: The question should be, has the line been clearly drawn by precedent?

Docherty: Perhaps the easiest thing would be to answer this in connection with regulations, such as ICC regulations. In some instances a Federal regulation or even a state or municipal regulation, if violated in connection with the transportation of explosives, may very well amount to negligence by itself. Proof of violation of the regulation is all that is necessary to impose liability as to the class of people protected by the regulation. This is negligence and you may be responsible for making them whole. If the violation is deliberate or if there seems to be wrongful intent - usually criminal law requires intent as distinct from just carelessness - if there is wrongful intent or gross carelessness or something like that, perhaps a deliberate failure to adhere to the ICC regulation, and there is a death or a serious explosion, there can be criminal liability. It might go up to $10,000 or some years in jail. I think perhaps the answer to your

question is if the court finds more than mere carelessness, mere failure to use reasonable care, or if the court finds that there is deliberate intent - possibly a deliberate willful wrong, there may be criminal liability.

Dr. Damon, BuMines: You referred to Public Law 85-804, is that similar to or the same as the Price-Anderson Act?

Docherty: No, the Price-Anderson Act is the AEC Act and, without going into too much detail, that permits the AEC to indemnify contractors or licensees up to $500,000,000 for a nuclear incident. I understand if a defective airplane hits a nuclear installation, and there's public liability of any kind, the airplane manufacturer might also be indemnified. The indemnification is very broad and its almost automatic and I think that's what some people like about it. Public Law 85-804 is quite different. Its on the case by case basis although there are standard provisions in the Armed Services Procurement Regulations. If you get it put in, P.L. 85-804 protects you; it protects the contractor against indemnification for listed hazards and also a clause can be put in with the consent of the Government contracting officer indemnifying sub-contractors so that ultimately it protects the sub-contractor too. The difficulty with 85-804 is that nobody is quite sure, at least I'm not and a lot of people aren't, of just how much indemnification authority you get. Under the Price-Anderson Act you get $500,000,000. Under Public Law 85-804 you may not have much of anything.

Jezek, AMC: You covered this bit on being negligent. What about this phase that comes in of failure to warn? I know of a case where the claimant said he wasn't warned properly and he sued, not the Government, but a contractor. Could you cover that a little please.

Docherty: Well, I think you're getting into something akin to the product liability area. There is a definite requirement that if you put - I'm talking now not about the Government so much as a private concern, a manufacturer - if you put a dangerous product on the market and if it will blow up if you look at it cross-wise, you should say so on the front of it. If there is some danger, you can be liable and that liability can go beyond the immediate purchaser - a manufacturer may put this on the market and he's not only responsible to the person he sells it to, the wholesaler or retailer; he may be responsible for failure to warn someone who buys it from them. As the law is developing today, he may even be liable to someone who happens to be near and also gets injured. This is really akin to the product liability law and that has developed rapidly in recent years. The product liability theory is this, if you manufacture something dangerous, you're the one who knows most about it. The general public today in a complicated society can't be expected to test it. They can't take the thing out and test it and you've got to be sure that

its designed for its purpose and won't explode when they use it for that purpose. If there's some danger in it that they should know about, you've got to warn them. And that liability can go right thru several hands to the ultimate user and I think it would be true of something the Government used. If the Government bought something and put it out among its personnel for example and the thing exploded because there wasn't a warning on it, I think that Government personnel might very well be able to sue the manufacturer, even thru two or three hands. That would be the product liability theory in its general applicability.

Bishoff: This is not a question, this is my own reflection of your very fine presentation. It seems to me as the years have gone by and we've gotten away from the first point of negligence in causing the accident, there is apparently a trend to give the plaintiff money because of the accident and it seems to me that there's a good chance that both the Government and the contractor will have to pay these damages in the future. So the point that I would like to make is that our job in preventing accidents becomes more and more important as the years go by.

Docherty: I think that's an excellent observation. Someone asked me informally about safety regulations, whether you could avoid liability by not having safety regulations. I think that is definitely the wrong approach; the way to avoid liability is not to have accidents. There's one point that might interest you. This case that I just spoke about where the Circuit Court of Appeals reversed the lower court. It was a matter of what they call vicarious liability, whether you are liable if you hire an independent contractor to do a job for you; are you liable for his negligence or his actions and the general rule is "no." If you hire a chauffeur and he is your servant acting under your orders and he goes out an injures someone negligently, you are liable. But if you hire an independent contractor to do something for you, if you select him carefully and do everything reasonable and are not negligent yourself, you're not responsible. But there is a rule beginning to develop in the cases where the activity is extra-hazardous, here you may have a sort of a non-delegable duty and I think that was what the lower court thought. The Circuit Court of Appeals refused to apply this rule to suits by a contractor's employees. Perhaps the District Court's views may represent the wave of the future on these things. It may be in line with the general tendency to impose greater and greater liability on those concerned with extra-hazardous activities.

THE USE OF FIBROUS REINFORCED CONCRETE IN STRUCTURES EXPOSED TO EXPLOSIVES HAZARDS

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Abstract

The development of a shatter resistant concrete for use in structures where explosives are manufactured or stored is discussed. Short lengths of nylon or small diameter steel wires are incorporated into the concrete during the mixing process to insure random distribution. Fibrous reinforced slabs 32 x 32 x 4 inches were tested using a 10-pound charge as the loading mechanism. Data are presented to show that the use of fibres not only reduces the amount of fragmentation of concrete subjected to explosive loadings, but also reduces substantially the velocity of the fragments.

Introduction

The problem of preventing propagation of accidental detonations during the manufacturing and storing of explosives has been under investigation for a considerable length of time. One of the methods proposed as a partial solution to this problem has been to construct dividing walls of a material or materials that will not produce secondary fragments, under explosive loadings, of sufficient mass and velocity to cause detonation of adjacent explosives. Since January 1963, the Ohio River Division Laboratories of the U. S. Army Corps of Engineers has been investigating the use of short lengths of small diameter wires and synthetic fibres as random reinforcing for portland cement concrete(1). One of the objectives of this investigation is to develop a shock resistant concrete for use in underground structures subjected to shock waves from a nuclear explosion. More recently, studies have been underway to determine the effectiveness of dividing walls made of random reinforced concrete when subjected to loadings from chemical high-explosives.

The fibrous concrete investigation at the Ohio River Division Laboratories was initiated as a result of studies made under the direction of S. Goldfein at Fort Belvoir, Virginia(2), and by Dr. James P. Romualdi at Carnegie Institute of Technology(3). Both of these studies showed that the impact and shatter resistance of concrete can be greatly improved by the addition of randomly distributed fibres.

Materials

The fibrous materials tested in the dividing wall study included: steel wires ranging in diameter from 0.010 to 0.032-inch and one to three inches in length, 15 denier x 3/4-inch multifilament and 0.010 x 3-inch monofilament nylon, chyrsotile asbestos ranging down in length from one-quarter inch, and various sizes and lengths of polypropylene and polyethylene. All of the fibres were effective to some degree, but the two most effective were the 0.017 x 1 1/2-inch wire and the 15 denier x 3/4-inch nylon. Most of the tests were conducted using these two materials. Conventional reinforcement consisted of 4 x 4 - 8/8 welded wire mesh, or No. 3 reinforcing bars. Figure 1 shows some of the fibres as they would be used in concrete.

The concrete for all the test specimens was made using 3/8-inch maximum size aggregate, with mix proportions by weight of 1:2.14:1.15. The water cement ratio was 0.60, and the air content varied from 6 to 8 per cent. The proportioning of the fibres was by volume, and is expressed as a percentage of the absolute volume of the cement, sand, water, and air. The fibres were incorporated into the concrete during the mixing process.

Properties of Fibrous Concrete

Static bond tests showed that the 17-mil wire developed a bond strength of 570 psi in concrete similar to that used in the test program. This would mean that 56 per cent of the ultimate tensile strength of the wire was being utilized. The 10-mil nylon developed only 20 psi in bond, or approximately 10 per cent of the ultimate tensile strength of the nylon. No bond tests were conducted on the 15-denier nylon; however, based upon results of the slab tests, it appears that this material develops a slightly greater bond than does the 10-mil nylon. Despite the low bond strength of the nylon, its use as random reinforcement greatly increases the energy absorption characteristics of concrete. This can be seen in Figures 2, 3, and 4, which are load-deflection curves for plain, nylon reinforced, and wire reinforced flexural test specimens. If the areas under these curves are an indication of the strain energy absorption characteristics of the concrete, it is easily seen that the fibre reinforced concrete is far superior to the plain concrete. Dynamic tensile tests described in Reference 1 have shown that fibrous reinforced concrete will withstand tensile stresses in excess of five times that of plain concrete.

Test Procedures

Explosive tests were conducted on plain and fibrous reinforced concrete slabs with dimensions 32 x 32 x 4 inches. The charge used was a bare 10-pound cylinder of Composition B. This represented at one-third scale a wall 8.0 x 8.0 x 1.0 feet and a charge of 273 pounds.

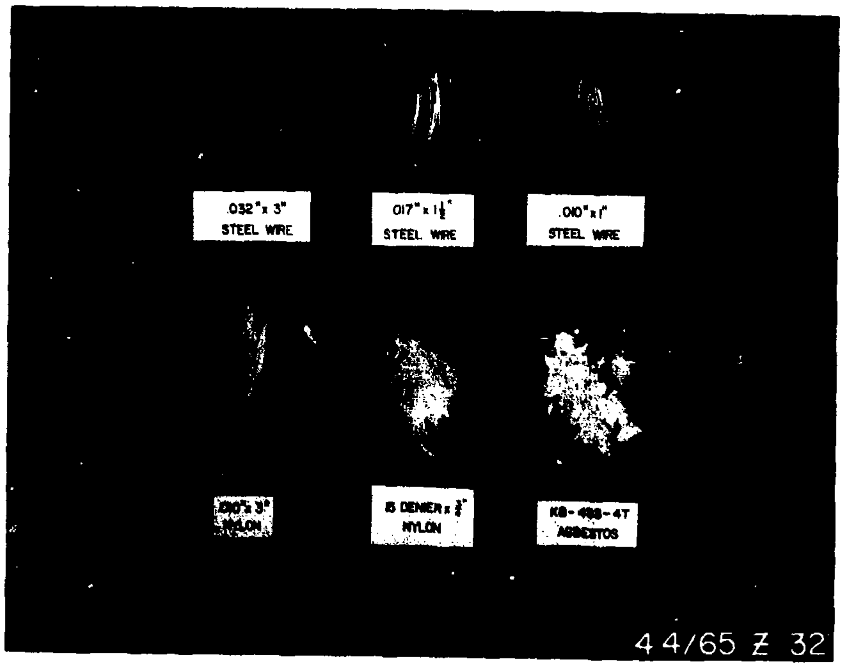

Figure 1. Fibres used in concrete as random reinforcement.

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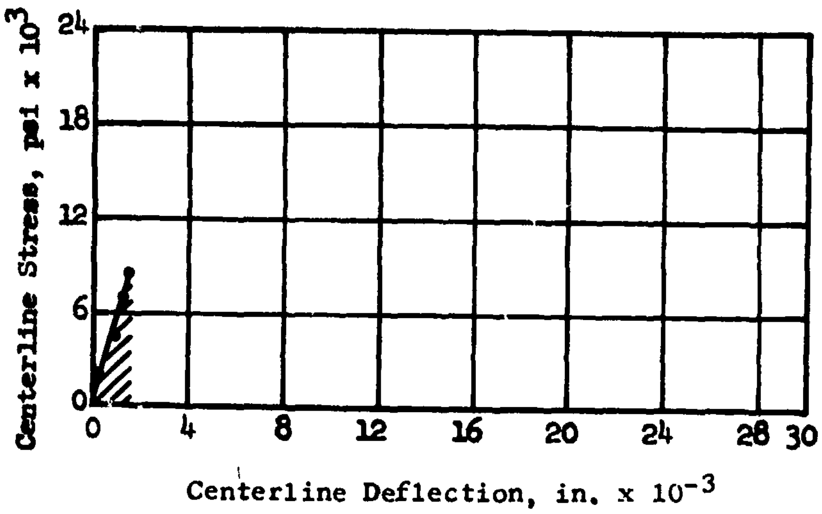

Fig. 2 Load - Deflection Curve for 3 1/2 x 4 1/2 x 16-inch Plain Concrete Beam. Maximum Size Aggregate used was 3/8-inch.

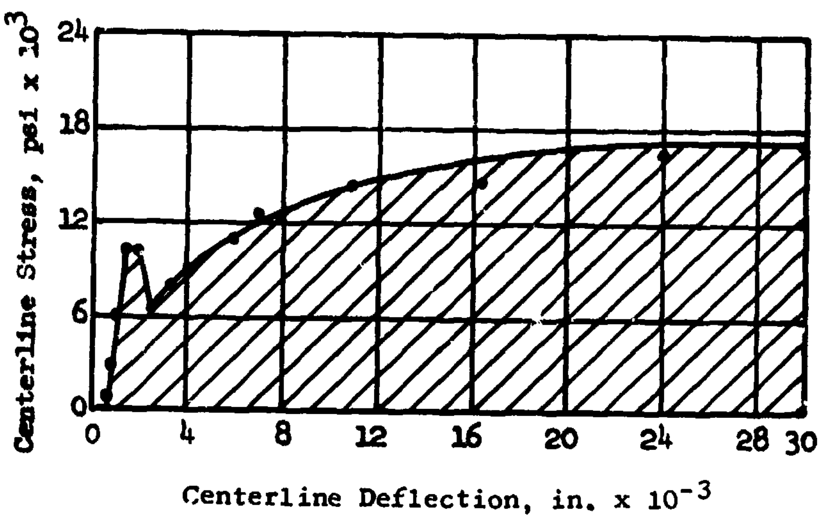

Fig. 3 Load - Deflection Curve for 2 x 2 x 6-inch Nylon-Reinforced Neat Cement Beam. Reinforcement was 4.2% of .010" x 3" Nylon Monofilament.

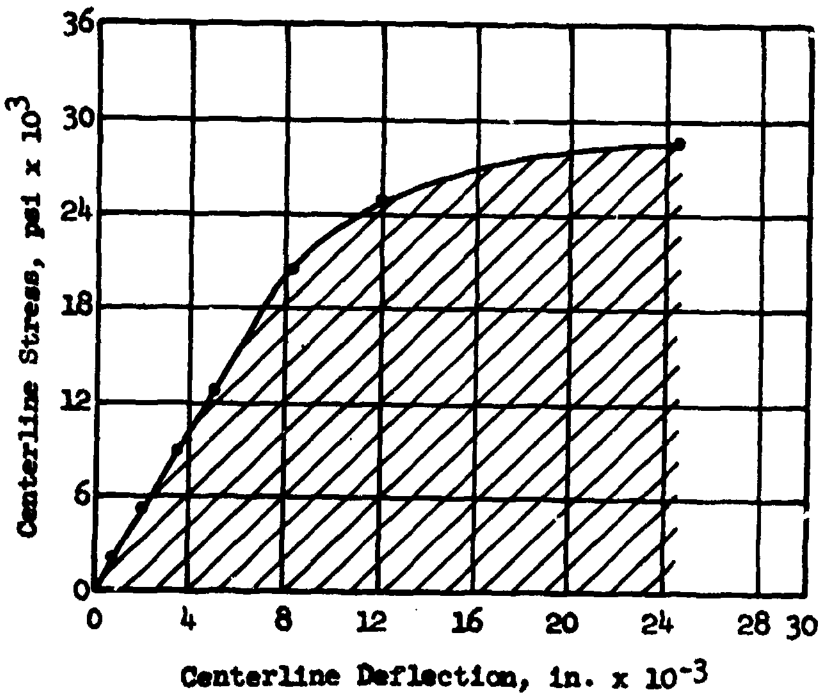

Fig. 4 Load - Deflection Curve for 2 x 2 x 6-inch Wire Reinforced Concrete Beam. Reinforcement was 1.96% of .017" x 1 1/2" Steel Wire. Maximum Size Aggregate used was No. 8.

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The dimensions of the wall were scaled linearly; the charge was scaled such that one-third of the cube root of the full scale charge equaled the cube root of the scaled charge. The slabs were tested in a vertical position with 4 inches of bearing on the two vertical sides. The center of the charge was placed 13 inches from the face of the slab and at the center of the slab. This gave a scaled distance factor $R / W^{1/3}$ of 0.50. Figure 5 shows a slab in position for testing. High speed photography was used to obtain fragment velocities.

Test Results

One phase of the program was concerned with the evaluation of the fibres when used in conjunction with wire mesh. The type of slabs tested, and the results of these tests are shown in Table 1.

Table 1

Evaluation of Slabs With Wire Mesh

No. of Tests	Reinforcing	Average Maximum Fragment Velocity
2	None	240 ft./sec.
2	4 x 4 - 8/8 wire mesh, E.F.	244 ft./sec.
4	2.5%, .010" x 3" nylon 4 x 4 - 8/8 wire mesh, E.F.	221 ft./sec.
3	2.5%, .017" x 1 1/2" wire 4 x 4 - 8/8 wire mesh, E.F.	185 ft./sec.

Using the fragment velocity of the unreinforced slabs as a base, it is seen that the use of wire and nylon fibres will reduce velocities 23 per cent and 8 per cent respectively. However, the number of fragments produced by the fibrous concrete is considerably less than that from the slabs without fibres. This is shown in Figures 6-9 incl. The slabs without fibres disintegrate completely, while those with fibres, though failed due to the large flexural stress, resist fragmenting to a great degree.

A second phase of the program was concerned with the evaluation of the fibres when used in conjunction with sufficient reinforcing to withstand the large flexural stresses. A description of these test slabs and the results are shown in Table 2.

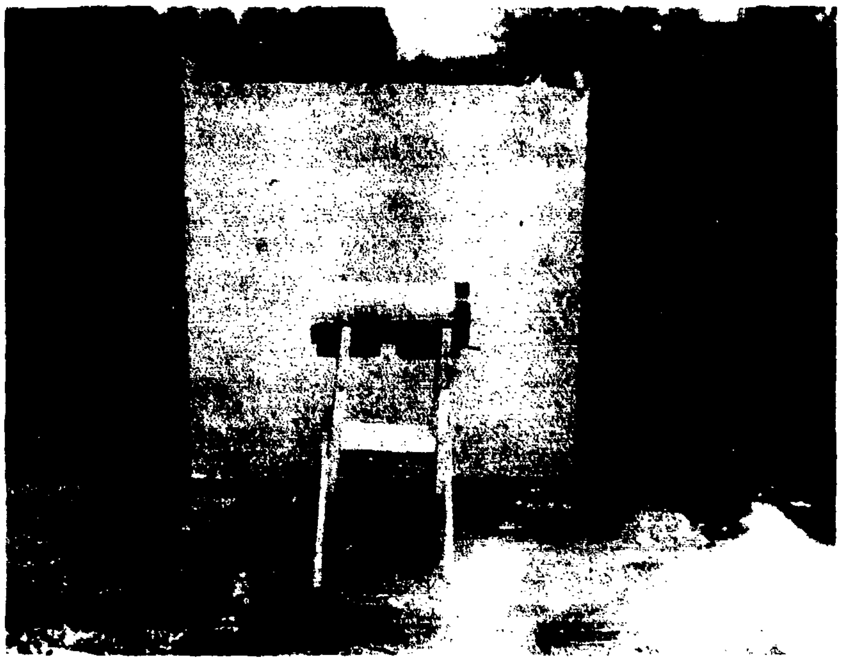

Figure 5. Fibrous concrete slab, 32 x 32 x 4 inches in position for testing with 10-lb. charge of Composition B.

Figure 6. Plain concrete slab after being subjected to a 10-lb. charge of HB.

Figure 7. Concrete slab that was reinforced with 4 x 4-8/8 wire mesh on each face, after being subjected to a 10-lb. charge of HB.

Figure 8. Concrete slab that was reinforced with 4 x 4-8/8 wire mesh on each face and 2.5% of .017" x 1 1/2" steel wires, after being subjected to a 10-lb. charge of HB.

Figure 9. Concrete slab that was reinforced with 4 x 4-8/8 wire mesh on each face and 2.5% of .010" x 3" nylon fibres, after being subjected to a 10-lb. charge of HB.

Table 2

Evaluation of Slabs With Reinforcing Bars

No. of Tests	Reinforcing	Maximum Fragment Velocity
1	No. 3 bars @ 4" o.c. each way, each face	253 ft./sec.
1	No. 3 bars @ 4" o.c. e.w., e.f., with tie bar*	253 ft./sec.
1	1-3/4% - 15 denier x 3/4" nylon and No. 3 bars @ 4" o.c., e.w., e.f., with tie bar	202 ft./sec.
1	1-3/4% - .017" x 1 1/2" wire and No. 3 bars @ 4" o.c., e.w., e.f., with tie bar	208 ft./sec.

*See Figure 10

Again, using the slabs without fibres as a base, it is seen that the fragment velocities are decreased 20 per cent and 18 per cent by the nylon and wire fibres respectively. The four tested slabs are shown in Figures 11-14 incl. The slabs without fibres, though heavily reinforced, disintegrated completely, while the fibrous reinforced slabs remained fairly intact, though failed in flexure. It should be pointed out that the excessive bending of the slab made with wire fibres (Figure 14) was due to bond failure of some of the reinforcing bars. This was caused by insufficient concrete cover of one part of the reinforcing mat.

Conclusions

These studies indicate that randomly distributed fibres as reinforcing in concrete considerably increase the shatter resistance of the concrete when subjected to explosive loadings. In addition, the fibres help decrease the velocity of the concrete fragments produced by the explosive forces.

Figure 10. Reinforcing used in the slabs shown in Figures 12, 13, and 14. Notice the bent bar that ties the two mats together.

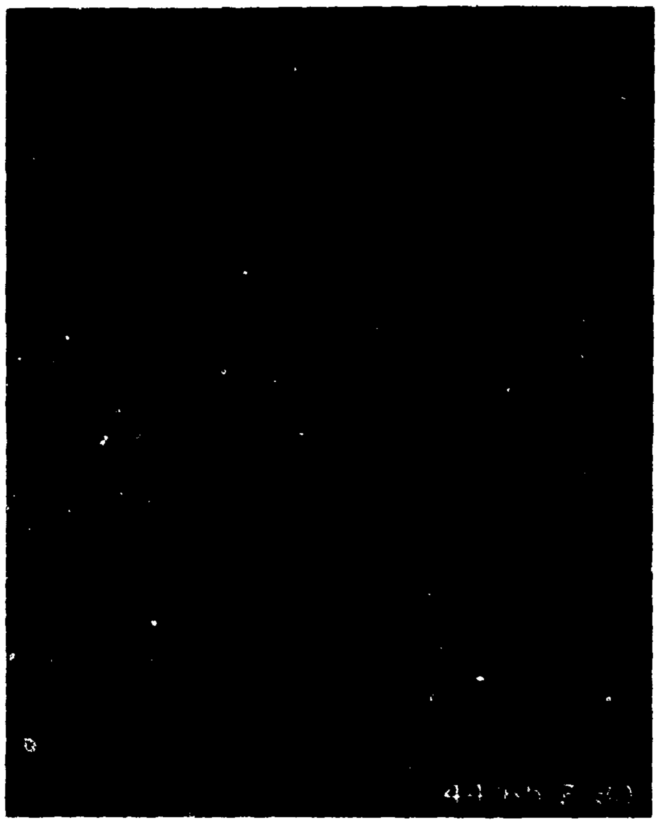

Figure 11. Shown is what remained of a concrete slab reinforced with No. 3 bars @ 4" on center, each way, each face. There was no tie between mats, and no fibres in the concrete. A 10-lb. charge of HE was used to load the slab.

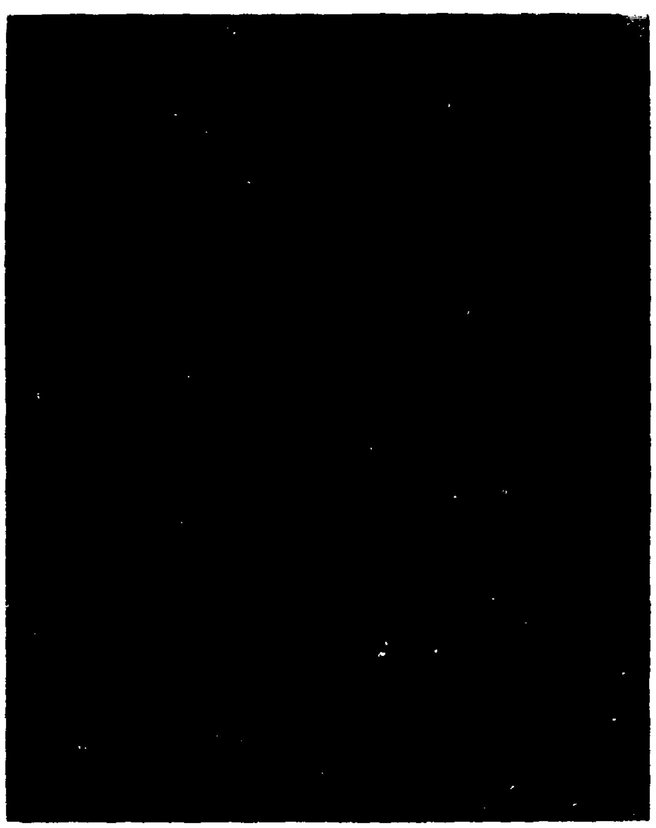

Figure 12. This is what remained of a concrete slab reinforced the same as the slab above except for a bar 4" on center tieing the two mats together, as shown in Figure 10. The concrete did not contain any fibres.

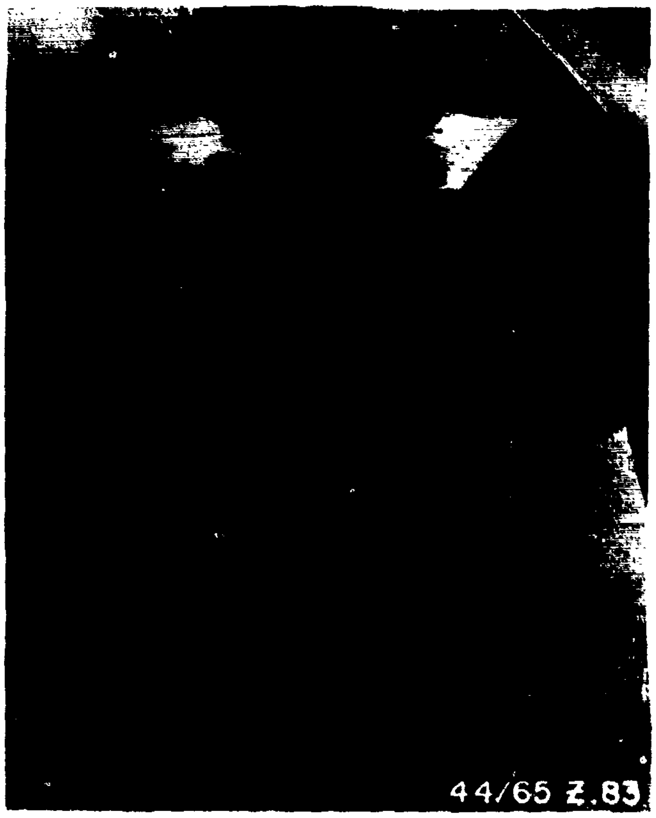

Figure 13. A fibrous reinforced concrete slab after being subjected to a 10-lb. charge of HE. In addition to reinforcing bars as shown in Figure 10, the slab contained 1 3/4% of 15-denier x 3/4" nylon fibres.

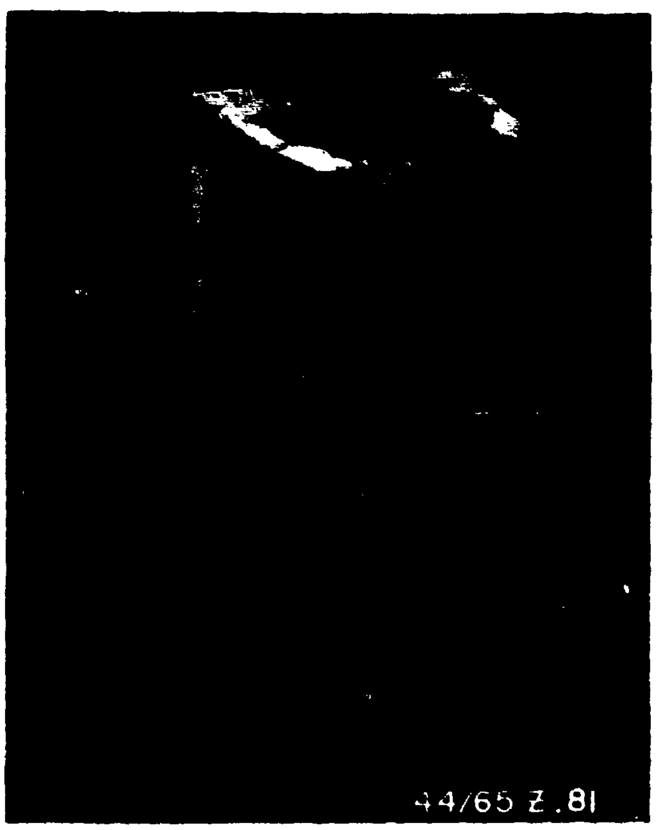

Figure 14. This slab was similar to that shown above except that it contained 1 3/4% of .017" x 1 1/2" steel wires rather than nylon.

ACKNOWLEDGMENT

The studies discussed in this paper were directed by the Missiless and Protective Structures Branch, Engineering Division, Directorate of Military Construction, Office, Chief of Engineers, U. S. Army.

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(2) J. Goldfein, "Plastic Fibrous Reinforcement for Portland Cements," U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia, Technical Report 1757-TR, October 1963.

(3) J. P. Romualdi and G. B. Batson, "Mechanics of Crack Arrest in Concrete," Journal of the Engineering Mechanics Division, Ann Arbor, Michigan, Volume 89, No. EM 3, June 1963.

Wenzel, GM: Have you tried to test your concrete in your laminated form, meaning, put something in front of it like plywood or plastic?

Williamson: No, we haven't done that but we have put a 2" core of luminum honeycomb and polyurethane foam in the center of the slabs and put 2" of concrete on either side. These weren't very successful, the shock absorbing materials were compressed to 1/4 or 1/2" indicating that they did function but apparently there wasn't enough of the material in them.

Webb: How severe is the bundling in the material during mixing?

Williamson: There are techniques needed to mix this material. You are not just able to throw them in and have them disperse the way aggregate does. There are some materials that have better mixing properties than others. The 15 denier nylon you can just throw in and it will mix thoroughly and disperse. The 10 mil x 3" nylon we use a blower to blow it in the mixer and drum as it revolves. The wires are best incorporated by placing them on sheets with vibrators and allowing them to vibrate into the mix. There is a length diameter ratio which can't be exceeded, otherwise the materials will just ball up in the concrete, if the length diameter ratio is 100 or 120. If you exceed this ratio then you get nothing but little balls of wire dispersed throughout the concrete. Its not effective at all. We are working also on trying to improve the mixing capabilities and hope to do this also.

Couch, UTC: Did you say the patent applied only to the steel wires?

Williamson: Right.

Couch: No matter what method they're used?

Williamson: Well all I know is they have applied for the patent of incorporating the wires into the concrete and they haven't specified how they were put in.

Nolan, DCASR: Has any thought been given to using fibreglass instead of nylon?

Williamson: Yes, we have tried fibreglass but the bond was so low that the results were very poor. We tried using fibreglass that was vinyl-coated and the bond between the vinyl and the fibreglass was also poor. Neither one was successful, however, fibreglass is probably the strongest synthetic fibre there is and we're still looking into it with the idea of getting something that has a coating on there that will give us a good bond.

<u>Zugschwerdt, Holston Def Corp</u>: Have you done any work with thick walls that would be used in between to see whether this will cut down spalling in a wall of say a foot or 15" thick?

<u>Williamson:</u> We have never tried it that thick but there will be some tests run later this summer I believe by Picatinny Arsenal for us to determine this. But the fact that there was such little spalling with the 4" slabs should indicate that we shouldn't get very much from thicker slabs.

HAZARDS OF PNEUMATIC TRANSPORT OF SOLID EXPLOSIVES

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ABSTRACT

This paper presents the results of an investigation of the hazards involved in pneumatically transporting solid explosive materials.

Consideration is given to the theory of pneumatic transport and the effect of flow parameter variations on transport conditions. Experimental data are presented to substantiate the theoretical considerations and to define previously uninvestigated parameter interrelations. The factors considered are particle size and shape, material flow density, transfer line size, acceleration distance and mode of particle flow. An applicable correlation of conditions is presented, and the application of results obtained on an experimental scale to process operations is discussed.

The sensitivity and reaction of explosive materials to the forces and energies encountered during pneumatic transport are discussed. Factors of prime importance considered are initiation of material by impingement with transport system components or by inter-particle collision, the transition to explosive reaction through initiation of secondary reaction in dust-laden atmospheres, and the generation of explosive dusts. Test methods for determining impingement sensitivity as a function of particle velocity are presented. The effects of system configuration and materials of fabrication on impingement sensitivity are discussed.

Methods of reducing hazards, such as modifying the system design setting operating limits, and using inert atmosphere, are considered.

*Presented by

I. INTRODUCTION

The purpose of this paper is to present the results of a study of potential hazards involved in conveying solid explosives by pneumatic transport. Pneumatic transport is defined as the movement of solids, termed the dispersed phase, by entrainment in a flowing fluid (air), called the continuous phase.

Because of the attractive features of pneumatic transport (lower handling cost, flexibility, adaptability to remote operation, and controllable atmospheric conditions), it has been increasingly used for processing and transporting solid explosive materials such as casting powder for the manufacture of solid propellants. Experience and hazard analyses, however, have shown that the factors influencing material behavior under transport conditions must be understood and evaluated to ensure effective, efficient, and safe operation of transport systems. To provide the needed understanding and evaluation, the subject investigation was undertaken. Data obtained during the course of this investigation indicate that the use of pneumatic conveying is not feasible for certain highly energetic materials because of the limitations imposed on operating conditions by the sensitivity of the transported material. This conclusion is based on consideration of hazardous conditions inherent in transport system designs, the sensitivity characteristics of explosive solids under transport conditions, physical relationships applicable to pneumatic transport design, and limits imposed upon operating conditions by safety considerations. The following discussion is limited to primary hazards; the summarized conclusions of previously published work are presented to clarify operating limits.

II. DISCUSSION

As would be expected, pneumatic transport of solid explosives entails more hazards than do inert materials commonly moved in this way. Of particular concern in pneumatic transport of cylindrically shaped casting powder (the primary material involved in this evaluation) is the sensitivity to impingement, friction and electrostatic discharge; the generation of electrostatic charges; and the presence of explosive dust/air mixtures and residual dust films.

A. Impingement

Impingement, as used in this study, is defined as the collision of a powder granule with a portion of the conveying system, another powder granule, or any object intentionally or unintentionally placed in the flow system. Impingement is an important consideration in pneumatic transport since it has been demonstrated that impingement may result in initiation and combustion of the conveyed powder or in partial initiation producing sufficient energy to initiate dust explosions.

1. Testing

Casting powder shows a degree of impingement sensitivity related to the chemical and physical properties of the material. The impingement sensitivity can be measured by impinging samples against a solid target and determining the particle velocity at which threshold impingement initiation or particle fracture occurs. The threshold impingement particle velocity is defined as that velocity at which ten trials fail to produce evidence of reaction (initiation or fracture), whereas the next higher test level will give evidence of reaction. Particle fracture results in poor product quality and

thus limits acceptable transport conditions. The threshold impingement particle velocities for several typical casting powder compositions are shown in Table I.

Initiation, defined as evidence of burning, flashes, or sparkles, is a limiting operating condition since it results in a hazardous condition. Differentiation is made between flash and sparkle initiation: flash is characteristic of CMDB formulations containing metal additive A (see Figure 1-A) and produces a localized light spot on time exposure film of an impingement test; sparkle is characteristic of formulations containing the more reactive metal B and results in multiple tendrils of light originating from the point of impingement on a similar film and test (see Figure 1-B). The sparkle reaction is due to the scintillating characteristic of metal additive B. Color photography has shown an apparent difference in intensity between flashes, which appear as dull yellow-white, and sparkles, which appear as brilliant, blue-white.

2. Effects of Construction Materials and System Configuration

A study was conducted to determine the effect of materials of construction and system configuration on impingement sensitivity. Table IIA shows the results of tests in which powder flow was directed at a 90-degree angle against mild steel, stainless steel, polyethylene, and rubber. No difference in threshold value was observed. High-speed photographic films showed that in the tests of impingement against the harder steel materials most of the reactions occurred on the face of the impingement target and a large amount of particle fracture resulted. Impingement against the softer polyethylene and rubber materials produced a larger percentage of high-velocity rebounding particles, causing most of the initiation reaction

to occur through inter-particle collision off the face of the impingement target. Particle fracture was less prevalent with the soft material.

In all cases, an increase in percentage of initiation or fracture was noted when particles hit in a mass rather than individually. Based on photographic observation, this effect is thought to be a direct result of an increase in momentum, i.e., the production of higher energies for a particle impacting against the target face where several following particles simultaneously collide with the impacting particle.

Results of tests using different angles of powder flow impingement are shown in Table IIB. Little or no effect of angle of the steel target is noted at these velocities.

To determine the effect of tube bends on flowing casting powder, powder was subjected to an $\sim 45^{\circ}$ change in direction in a glass tube. Results shown in Table IIC indicate that formulations containing metal B had the same threshold velocity as the 45° steel impingement test, while no reaction was observed for formulations containing the less reactive metal A to the limit of the test.

3. <u>Effects of Casting Powder Parameters</u>

The effect of casting powder quality variability upon impingement sensitivity (90-degree impingement angle) was evaluated. Uniformity within a given powder production lot established by testing random samples against mild steel at 90° impingement angle is excellent in formulations containing metal A and in those containing both metal A and B (Table IIIA). Uniformity from lot to lot was established by testing samples from selected lots of a given formulation against mild steel at 90°. Formulations containing metal A had excellent lot-to-lot uniformity but a formulation

containing metal B (Table IIIB) had only fair uniformity.

The tests previously described were performed with screened powder which contained essentially only individual granules. Since observation showed that unscreened samples of casting powder contain clusters of two or more granules, the effect of clusters was determined. A single granule sample of a powder lot containing metals A and B exhibited a threshold of 2,900 fpm; a sample of clusters from the same lot exhibited a reduced threshold of $<2,400$ fpm. The increased sensitivity in clusters is thought to be a result of higher momentum reached for the clusters than for individual particles at a given velocity.

B. Air Velocity vs. Powder Velocity

The powder velocity in a given transport system is dependent upon the physical characteristics of both the conveying system and the transported powder.

The critical threshold particle velocity established by impingement tests indicates that powder velocity must be considered in any analysis of a transport system. Since the air velocity in such a system is more feasible to measure, a study was made to determine an applicable correlation between air velocity and powder velocity. A fully detailed discussion of the theoretical reasons underlying the observed effects will not be undertaken in this report, but the important conclusions and applicable correlations are presented.

A definite distance is required to accelerate particles from rest (point of introduction into the air stream) to their ultimate velocity. In the small-scale (3/4-inch-ID tube) conveying system employed in the tests, this distance ($\sim$20 ft) decreased with increasing air velocity

(Figure 2) and increased with increased ratio of tube diameter to particle diameter (Table IV).

The ultimate velocity of the powder was found to be 50 to 55% of the air velocity in the small-scale test set-up. Ultimate particle velocity is increased by using smaller particles (Figure 3), or by increasing the ratio of tube diameter to particle diameter (Table IV). A decrease in percentage ultimate velocity in a fixed distance is noted with increasing air velocity (Figure 4).

Variation of individual particle velocities within the flow stream was determined using high-speed photography. Results (Figure 5) show the variations in particle velocities under transport conditions.

Consideration of these and other observed effects reveals that while a correlation applicable to the average particle velocity may be attempted, individual particles, due to their orientation and the complex inter-relationships of parameters, achieve velocities significantly above the average. Proper selection of conditions would admit the possibility of the velocity of an individual particle equaling the air velocity,and it is considered that the existence of one particle above the critical threshold impingement velocity results in a hazardous condition. Thus, it must be assumed that a particle velocity equal to the air velocity is the only acceptable correlation for analysis of the hazards of pneumatic transport of solid explosives.

The theoretical minimum air velocity necessary to transport casting powder is shown in Figure 6. Experiments have substantiated the 2,600 fpm minimum for vertical transport of 0.1354-inch powder granules. Since the minimum velocity for conveying is approximately the threshold impingement

velocity for large granules containing metals A or B (Table I), air transport of these powders is not feasible.

C. <u>Explosibility Characteristics of Propellant Material Dust-Laden Atmosphere</u>

The generation of dust is inevitable during pneumatic transport of solid explosives, and the initiation of the generated dust by electrostatic discharge or impingement reaction represents a potential hazard.

The three major requirements for producing a dust explosion for most finely divided combustible materials are (1) dispersed dust concentrations above the lower explosion level, (2) sufficient oxygen present to support combustion, and (3) source of initiation to heat a portion of the dust cloud to its ignition temperature. Dust explosion hazards are eliminated by one or more of the above conditions.

During casting powder manufacture, the potential for a dust explosion is present during processing operations in which dust-laden atmospheres are created. The dust explosion hazard is more acute in the solid propellant industry because the materials normally processed are explosives which generally require less energy for initiation and inherently contain additional oxygen to support combustion.

1. <u>Dust Composition and Particle Size</u>

In a study made to minimize dust explosion hazards in propellant processing systems at Allegany Ballistics Laboratory, the generation, accumulation, characterization of dust composition and particle size, and explosibility properties of several processing casting powder dusts were

investigated.

The Bureau of Mines "Hartmann" test apparatus and criteria were employed to establish the minimum explosion dust concentration and minimum electrostatic discharge initiation energy for various propellant materials. The test results reported herein should be regarded as relative values since they are influenced by factors such as the chemical and physical properties of the dust, uniformity of the dispersed dust cloud, ignition source and environmental conditions. Information concerning the Bureau of Mines dust explosibility tests and their findings in intensive investigations with many agricultural, industrial and chemical dusts can be found in References (1) through (5).

It becomes evident upon examination of data in Tables V and VI that the composition and particle size of dust residue vary considerably in the various casting powder processing areas. In general, analysis shows the primary dust constituents to be binder, oxidizer and metal additives. Although microscopic examination showed the dust obtained from different processing areas to vary widely in particle size (Table VI), the mean for particle size for most dust was low.

The ability of propellant ingredients and casting powder dust residues to form explosive mixtures when dispersed in air is demonstrated by data in Table VII. In summary, these data show that finely divided dust dispersions of individual propellant ingredients, except AP and graphite, have low explosion concentrations in air and are initiated by an electrostatic discharge spark at low energy levels. Individually, AP and graphite dust-laden air explosion concentrations are in excess of 0.813 oz/ft^3 and

could not be initiated up to the limits of the electrostatic discharge test apparatus at this concentration.

2. Use of Inert Atmosphere to Eliminate Dust

As pointed out earlier, elimination of one or more of the conditions necessary for a dust explosion would eliminate this hazard during normal transport. Blanketing with an inert gas is one means by which oxygen, except for that in the binder and solid oxidizer, can be removed from within the explosion space.

The use of inert atmospheres for minimizing dust explosions has been investigated by the Bureau of Mines. Published data show inert gases such as argon, nitrogen and helium to effectively suppress initiation of metal B dust dispersions by electrostatic discharge spark when the oxygen concentration in the explosion space is kept low. Of these three inert gas candidates, argon appears to be the best choice because of its density and compatibility with ingredient dusts.

To substantiate the benefits of argon indicated by the Bureau of Mines study, explosibility tests were made at this Laboratory and the results showed the use of argon to be an effective means of suppressing initiation of casting powder dust dispersions by significantly increasing the minimum dust concentration and electrostatic discharge spark energy required for explosion of the dust mixtures tested (see Table VII). As shown in Table VII and Figure 7, argon appears to be a more effective suppressant for ingredients and dust mixtures containing substantial quantities of metal B than for oxygen-balanced mixtures or mixtures having the ingredients AP and NC as the major constituents. Experimental data, when

analyzed in terms of the calculated oxygen available to support combustion, show the lowest minimum dust explosive concentration for a system such as AP/NC to occur at the point of oxygen balance under argon. Thus, should process dust residue contain substantial quantities of the ingredients AP and NC within the critical ratios or, more important, be oxygen-balanced under argon (as shown in Figure 7), then only marginal benefits could be expected with the use of this inert atmosphere (see Table VII).

Previously in this paper, it was shown that base-grain containing metal B exhibits sparkling characteristics when powder velocities exceed a minimum impingement threshold value. It has been postulated that these sparkles could initiate dust/air mixtures.

Tests were made with the apparatus depicted in Figure 8, and the results were photographed using high-speed film. It was found that ingredients, their synthetic mixtures and casting powder residue dust dispersions in air could be initiated at relatively low dust concentrations by sparkles resulting from impinged casting powder containing metal B (see Table VIII). Argon appears to be an effective initiation suppressant for metal B or dust mixtures containing large amounts of metal B but only marginal for dust mixtures which are nearly oxygen-balanced.

3. Conclusion

The explosibility of dusts serves to stress the need for (1) eliminating all operations which could cause sparkling of base grain, (2) eliminating the generation and accumulation of casting powder dust residue, and (3) using an inert atmosphere such as argon to suppress initiation should sparkling and/or electrostatic discharge occur in the presence of dust.

D. Initiation in Valving

Valves must be used to control the flow of explosive material during transport. Because of the usual impact and friction sensitivity of the solid explosive materials being handled, the forces and energies generated during valve operation may result in hazardous conditions. Several commercial valves were evaluated for possible hazards during operation. The characteristics, resultant hazards, and recommendations for these valves are given in Table IX. In general, all the valves are undesirable because of high velocity of operation, metal-to-metal contact in the presence of explosive dust, and the positive air pressure required for the valves to remain closed.

An external pinch bar valve, specially redesigned by Allegany Ballistics Laboratory for fail-safe operation with casting powder, was evaluated and found acceptable. The redesign features of this valve include incorporation of a spring to maintain the closed position, installation of a bleed orifice to produce low operating velocity, the use of a dust-tight bellows to exclude dust from points of possible metal-to-metal contact, replacement of metal components with materials of lower coefficient of friction, and the use of conductive rubber for the valve boot. The characteristics of this valve are shown in Table IX and the valve is pictured in Figure 9.

E. Transition and Propagation in Conveying Systems

Explosive materials under certain conditions of configuration and confinement will transit from flame initiation to explosion or propagate a reaction initiated by an explosive donor. Investigations of the

configuration of conveying systems will reveal areas in which initiation may result in explosive reaction.

A likely area for transition to occur in pneumatic transport system is in tanks, hoppers, and valved lines. The exact nature of transition characteristics in conical hoppers has not been determined; however, the length, diameter and degree of confinement of discharge spouts can be used as criteria for evaluating the possible transition hazards. Transition hazards exist in any tank where the length of the vertical discharge spout exceeds the critical height for the diameter of the spout. Similarly for valves, when the height of the explosive material bed contained by the valve exceeds the critical height (based on the valve diameter), a transition hazard exists. Since valves are generally employed on discharge spouts of hoppers, the combined height of material in valve and spout must be considered when analyzing for transition hazards.

The propagation characteristics of the transport system become important when an explosion occurs at some point. Whether this explosion will be transmitted throughout the entire system depends upon the presence or absence of a propagation train. Since it is generally not feasible to design a conveying system having line diameters smaller than the critical diameter for most explosive materials, it should be assumed that an explosion in one section of a conveying system will result in total destruction of the system.

Simulated testing has demonstrated that it is not necessary to have a continuous explosive train to propagate an explosive reaction in a

transfer system. The reaction products produced by an explosion can be transmitted down the transfer tube and initiate reaction in material at the opposite end. Therefore, a transfer system with no explosive in the lines but with explosive in two separated hoppers connected by a transfer line can be totally destroyed by an explosion initiated in only one hopper. This can be controlled by the proper sequencing of valves or by use of interlocks between hoppers and conveying lines. Thus, for safe operation, emphasis must be placed upon eliminating initiation and transition hazards.

III. SUMMARY AND CONCLUSIONS

Impingement is an important consideration in establishing the limiting conditions for pneumatic transport. A definite threshold reaction level exists above which initiation, usually characterized by sparkling or flashing, occurs for most materials tested. As sparkling has been shown to be sufficiently energetic to initiate dust dispersions, the particle velocity must be maintained below the threshold level. Studies of the effect of system design parameters show that little or no reduction of impingement sensitivity can be accomplished through design changes.

Consideration of the particle velocity - air velocity relationships shows that operation with an adequate margin of safety can be approached only by maintaining an air velocity lower than the threshold impingement particle velocity.

Dust will always be present during transport, and dust explosion hazards are to be expected. Such hazards, however, can be significantly reduced for composition other than an oxygen-balanced system by the use of inert atmospheres (such as argon). The electrostatic sensitivity of the dust, however, is of primary concern, and the margin of safety can be increased only by positive elimination of dust and/or initiation sources.

All valves used for control must be evaluated for hazards. Valves of the Allegany Ballistics Laboratory fail-safe design are recommended to control the flow of casting powder.

Material configuration can be the basis for transition hazards. Additional safety of operation can be gained by designing containers so

that material heights are below the critical height to explosion for the material being considered.

Propagation hazards will exist in most systems. Control of propagation through the use of proper valve sequencing or interlocks will increase the safety margin, but only the elimination of initiation will eliminate such hazards.

Applicable data on impingement, impact, friction, and electrostatic discharge sensitivity of the material to be transported must be obtained before the system can be evaluated for safety. Constant monitoring of the material to ensure that the sensitivity does not vary is mandatory.

Hazard analyses such as these serve to point out the necessity of considering all aspects of a processing system and the applicability of the information for modifying existing systems and establishing design criteria for new systems to provide an adequate margin of safety.

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TABLE I

TYPICAL IMPINGEMENT RESULTS

Type Casting Powder	Threshold Particle Velocity (FPM) Average	Range	Reaction
CMDB			
NC-NG-AP-metal A	8950	-	flash
NC-NG-AP-HMX-metal A	6100	-	fracture
NC-NG-HMX-metal B	3750	-	sparkle
High Rate CMDB (NC-NG-AP)			
plus metal A	3750	2900-6100[a]	flash
metal A & B	2900	2400-4050[b]	sparkle

(a) Represents evaluation of 47 powder lots. Includes variation in particle physical characteristics.

(b) Represents evaluation of 3 powder lots. Particle physical characteristics similar in all lots.

TABLE II

EFFECT OF CONVEYING SYSTEM CONFIGURATION ON IMPINGEMENT SENSITIVITY

A - Materials of Construction

Target Material	Threshold Impingement Initiation/Fracture Particle Velocity[a] Casting Powder (Metal A)	Casting Powder (Metal A & B)
Mild Steel	3750 FPM	2900 FPM
Stainless Steel	3750 FPM	2900 FPM
Polyethylene	3750 FPM	2900 FPM
Rubber	3750 FPM	2900 FPM

(a) Testing conducted with target set at 90° to the direction of powder flow.

TABLE II (cont'd.)

EFFECT OF CONVEYING SYSTEM CONFIGURATION ON IMPINGEMENT SENSITIVITY

B - Angle of Impingement*

Sample Designation	Threshold Impingement Initiation/Fracture Particle Velocity,[a] fpm			
	30°	45°	60°	90°
Casting Powder containing				
Metal A	-	4350	-	3750
Metal A & B (2.8% B)	-	3750	-	2900
Metal A & B (3.5% B)	2900	-	2900	2900

* Angle measured with the direction of powder flow.

(a)Testing conducted against mild steel target.

TABLE II (cont'd.)

EFFECT OF CONVEYING SYSTEM CONFIGURATION ON IMPINGEMENT SENSITIVITY

C - Tube Bends*

Sample Designation	Particle Velocity, fpm	Reaction
Casting Powder containing		
Metal A	7800[a]	none
Metal A & B	3750[b]	sparkle

* Testing conducted by subjecting powder flowing in a 3/4-inch-diameter glass tube to a 45° change in direction.

(a)Upper limit of test.
(b)Threshold velocity.

TABLE III

EFFECT OF PRODUCTION VARIATION ON IMPINGEMENT SENSITIVITY

A - Uniformity Within a Given Powder Lot*

Powder Containing Metal A	Theshold Impingement Initiation Particle Velocity,[a] fpm
Sample #1	3750
Sample #2	3750
Sample #3	3750
Sample #4	3750
Sample #5	3750
Powder Containing Metal A & B	
Sample #1	2900
Sample #2	2900
Sample #3	2900
Sample #4	2900
Sample #5	2900

* Tests were conducted on random samples.

(a) Testing conducted against a mild steel target set at 90° to the direction of powder flow.

TABLE III (cont'd.)

EFFECT OF PRODUCTION VARIATION ON IMPINGEMENT SENSITIVITY

B - Uniformity From Lot to Lot*

Sample Designation	Particle Size	Threshold Impingement Initiation/ Fracture Particle Velocity, fpm
Powder containing		
Metal A	90 x 105	4350
	150 x 150	3750
	150 x 150	3750
Metal A	133 x 144	4350
	126 x 136	3750
	129 x 138	3750
Metal A & B	131 x 142	4050
	134 x 143	2900
	134 x 142	2400

* Testing conducted against mild steel target set at 90° to the direction of powder flow.

TABLE IV

EFFECT OF TUBE/PARTICLE DIAMETER RATIO ON CONVEYING CONDITIONS

Tube Diameter (in)	Particle Diameter (mils)	Sample Size (gm)	Acceleration Distance (ft to ult. velocity)	Ult. Particle Velocity[a] (% of air vel.)
3/4[b]	135	25	16	50-55
3-1/2[c]	135	100	80	75-90

(a) Air velocity range of 6000-10,000 fpm.

(b) Data obtained in tests at ABL.

(c) Data obtained in tests at Radford Arsenal.

TABLE V

CASTING POWDER RESIDUE OBTAINED DURING PROCESSING

Casting Powder Residue[(a)]	Weight (lbs)	% of Total Residue
1. Clusters	7.25	36.40
2. Wafers	10.25	51.45
3. Large size metal B/Dust mixtures		
a) 420 - 840 μ	0.165	0.83
b) 250 - 420 μ	0.295	1.48
c) 125 - 250 μ	0.860	4.32
d) 53 - 125 μ	1.070	5.37
e) < 53 μ	0.030	0.15

(a) Casting powder residue (clusters, wafers, chips, staple and dust) obtained during screening of 1500 pounds of base grain. Residue was separated into individual constituents by a Rotap sieve arrangement.

TABLE VI

COMPOSITION AND PARTICLE SIZE
DISTRIBUTION OF DUST AND CASTING POWDER RESIDUE

Source	Composition (%)[a]				Particle Size (μ)	
	Binder	Oxidizer	Metal A	Metal B	Range[b]	Mean[c]
Casting Area[d]	10-27	21-55	8-26	0.1-0.2	1.6-1644	9
Screening Area[e]	18-36	34-57	11-30	0.0-1.0	6.8-1454	103
Generated[f]	22-26	38-41	15-19	5.3-5.4	0.8-612	6.7

(a) Range of values for samples examined.

(b) Smallest and largest particle size detected by microscopic examination.

(c) Arithmetical mean particle size from microscopic examination.

(d) Three samples examined.

(e) Six samples examined.

(f) Two samples examined.

TABLE VII-A

EXPLOSIBILITY CHARACTERISTICS OF DUST-LADEN ATMOSPHERES CONTAINING INGREDIENT(S) AND COMBINATIONS OF INGREDIENTS*

	Threshold Explosion Concentration (oz/ft^3) Air	Threshold Explosion Concentration (oz/ft^3) Argon[(a)]	Threshold Electrostatic Discharge Initiation Energy (joules) Air[(b)]	Threshold Electrostatic Discharge Initiation Energy (joules) Argon[(a,c)]
I. INGREDIENTS				
1. Fibrous NC	0.041	0.841	0.01	≥ 5.0
2. Metal B				
a) Powder	0.051	> 4.07	0.005	≥ 5.0
b) Large size	-	-	0.01[(c)(d)] 0.005[(c)(e)]	≥ 5.0
3. Metal A (Powder)	0.061	> 0.813	0.02	≥ 5.0
4. Ammonium Perchlorate	>0.813	> 0.813	≥ 5.0	≥ 5.0
5. HMX	0.474	> 0.813	0.02	≥ 5.0
6. Graphite	>0.813	> 0.813	5.0[(c)]	≥ 5.0
II. INGREDIENT COMBINATIONS				
1. AP/NC Dust Mixtures				
a) 75/25	0.242	0.267	0.20	1.2[(b)]
b) 50/50	0.061	0.122	0.20	1.2[(b)]
c) 25/75	0.043	0.282	0.06	1.2[(b)]

* Ingredients were screened individually (passed through 53 μ screen) and conditioned at 120°F for 24 hours prior to testing.

(a) System initially purged 5 minutes; combustion tube purged again four times at 15-second intervals prior to each trial.

(b) Sample weight of one gram (0.813 oz/ft^3) employed in these tests.

(c) Sample weight of two grams (1.63 oz/ft^3) employed in these tests.

(d) Threshold nonexplosion level as established by four consecutive failures.

(e) Threshold nonsparkling level as established by four consecutive failures.

TABLE VII-B

EXPLOSIBILITY CHARACTERISTICS OF SYNTHETIC DUST MIXTURES AND CASTING POWDER DUST RESIDUE*

	Threshold Explosion Concentration (oz/ft^3)		Threshold Electrostatic Discharge Initiation Energy (joules)	
	Air	Argon[a]	Air[b]	Argon[a]
I. SYNTHETIC DUST MIXTURES				
1. Perchlorated CMDB (Metal B, High %)	0.048	4.03	0.06[e]	≥ 5.0
2. Perchlorated CMDB (Metal A & B) (-9.5% O_2 in Argon)	0.043	0.187	0.06[e]	0.2[d]
3. Perchlorated CMDB (O_2-Balanced in Argon)	0.085	0.173	0.06[e]	0.2[e][f]
II. CASTING POWDER DUST RESIDUE				
1. Casting Area (Vac-U-Max)				
a) Sample 27-2	0.053	> 0.813	0.01	≥ 5.0
b) Sample 27-3	0.085	> 0.813	0.005	≥ 5.0
2. Screening Area				
a) Sample 2	0.204	> 0.813	1.2	≥ 5.0[d]
b) Sample 4	0.396	> 0.813	5.0	≥ 5.0[d]
3. Perchlorated CMDB (Metal B, High %)	0.630	4.06	0.06[e] < 0.01 > 0.005[f]	≥ 5.0
4. Perchlorated CMDB (Generated)	0.045	0.313	0.01	≥ 5.0[d]

* Samples were conditioned at 120°F for 24 hours prior to testing.

(a) System was initially purged for five minutes; combustion tube purged again four times at 15-second intervals before each trial.

(b) A sample weight of one gram (0.813 oz/ft^3) employed in these tests.

(c) Except where noted, a sample weight of two grams (1.63 oz/ft^3) employed in these tests.

(d) One gram sample (0.813 oz/ft^3) employed.

(e) Threshold nonexplosion level.

(f) Threshold nonsparkling level.

TABLE VIII

INITIATION OF PROPELLANT MATERIAL DUST-LADEN ATMOSPHERES BY SPARKLES RESULTING FROM IMPINGED BASE-GRAIN CONTAINING METAL B*

Dust Dispersion	Initiation by Sparkles Air[(a)]	Argon
I. INGREDIENTS		
1. Fibrous NC	Yes	-
2. Metal B (Powder)	Yes	No[(b)]
II. SYNTHETIC DUST MIXTURES		
1. Perchlorated CMDB		
a) With large size Metal A & B	Yes	Yes
b) With large size Metal B; Powdered A	Yes	Yes[(c)]
c) Oxygen balanced in Argon	Yes	Yes
III. CASTING POWDER RESIDUE		
1. Perchlorated CMDB		
a) Metal A & B (High % A)	Yes	-
b) Metal A & B (High % B)	Yes	-

* Dust dispersions created in modified Hartmann dust explosibility apparatus. Initiation source was sparkles produced in the immediate vicinity of the dust-laden atmosphere by impinging 25 grams of base-grain containing metal B against a steel target plate mounted in the combustion tube.

(a) Dust concentrations of 0.813 oz/ft^3 employed in these tests.

(b) Sparkles present, but no explosion of dust-laden atmosphere occurred for concentrations up to 5.69 oz/ft^3.

(c) Dust concentration of 5.69 oz/ft^3 required for explosion.

TABLE IX

COMPARISON OF VALVES FOR USE IN CONVEYING LINES

	Metal-Metal Contact in Presence of Explosive Dust	Velocity of Operation	Rubber Boot	Closed Position	Recommendation
Processing Control Valves*	Possible	High	Nonconductive. Electrostatic generation possible.	Relies on positive air pressure	Not acceptable for use with casting powder.
ABL-Designed Valves	Eliminated by use of dust-tight bellows and materials of fabrication	Low because of bleed orifice installed in air line.	Conductive	Spring used to hold closed position. Air to open.	Acceptable for use with casting powder.

*Valves tested include Syntron, RKL pinch-type and RKL peristaltic type.

Metal "A"

Metal "B"

FIGURE 1 G-1033
Typical Impingement Reaction

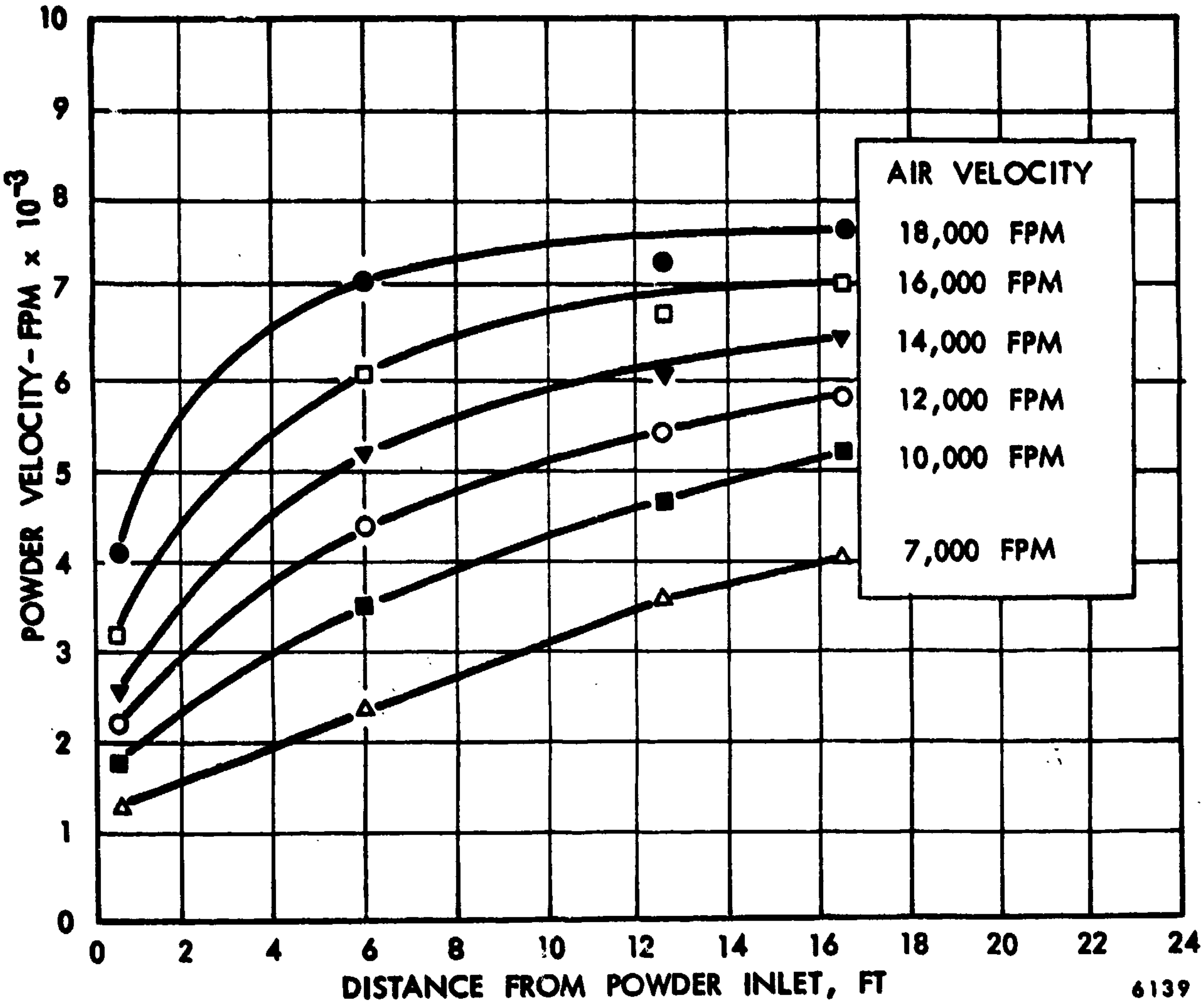


FIGURE 2
Distance to Maximum Particle Velocity
(3/4-Inch-I.D. Cellulose Acetate Tube and 0.135 x 0.135-Inch Dummy Powder)

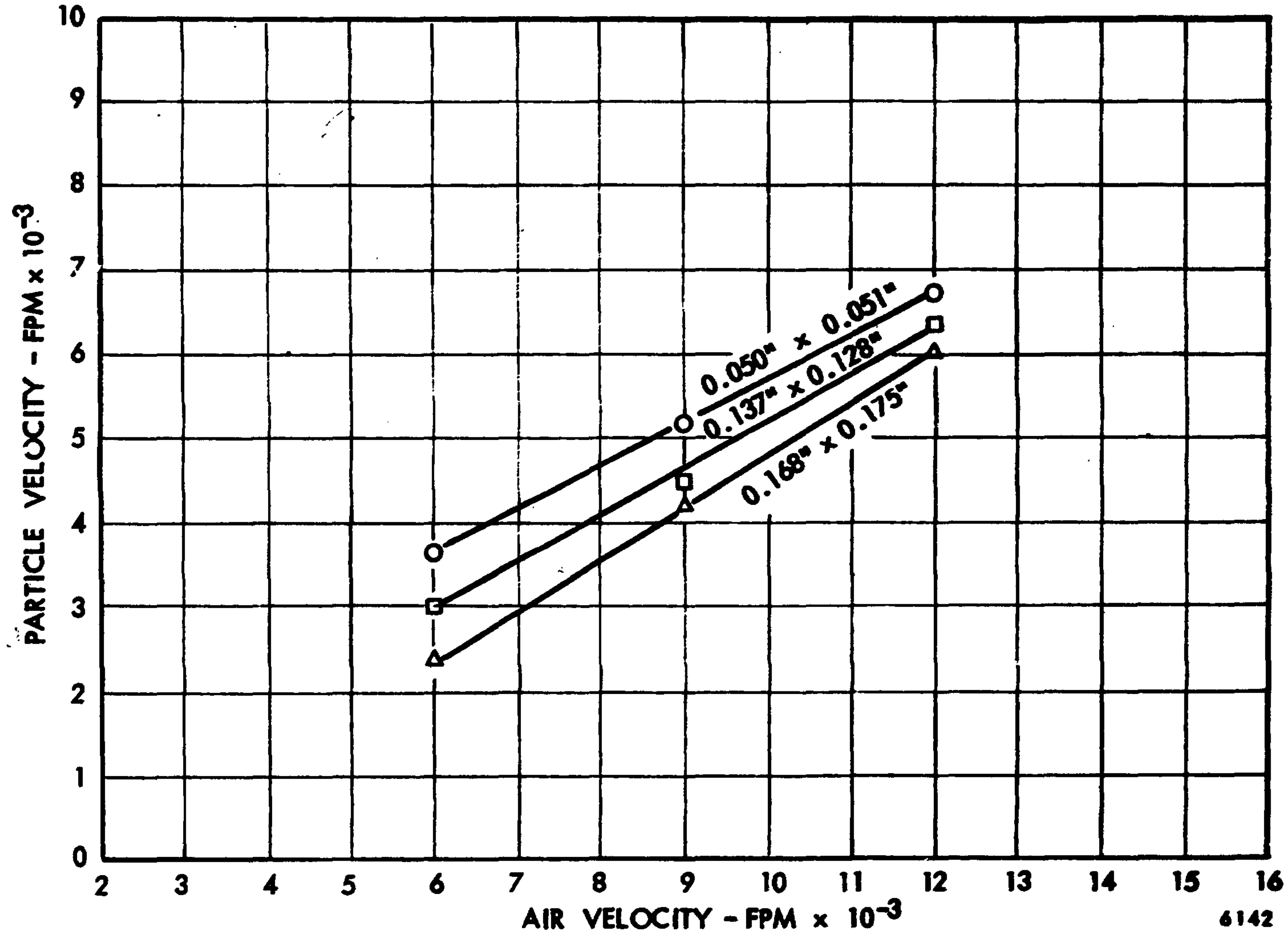


FIGURE 3
Effect of Particle Size on Air-Powder Velocity Correlation
(1-1/4-Inch Tube, Measured 30 Feet from Powder Inlet)

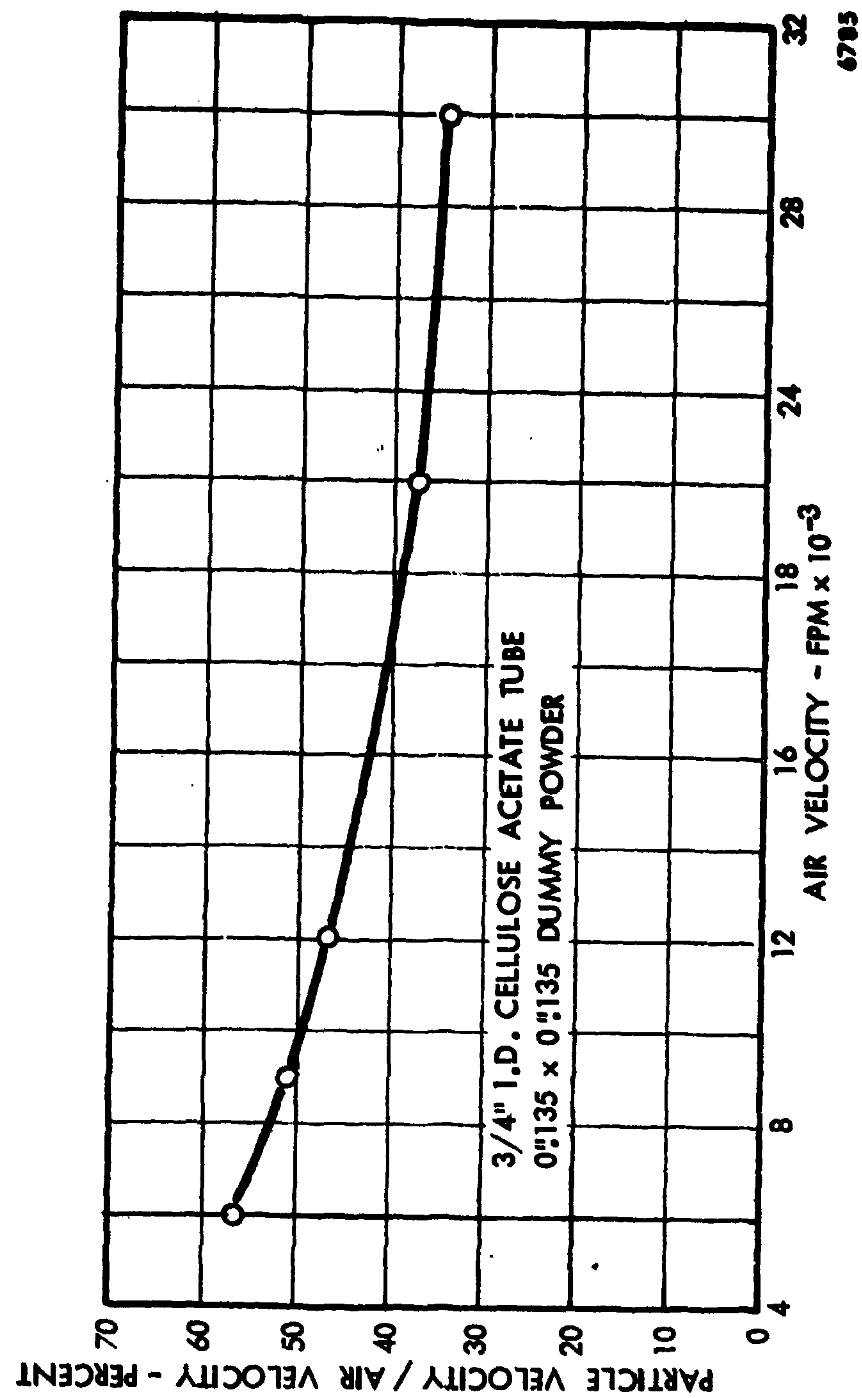


FIGURE 4
Percent Air Velocity Achieved By Powder

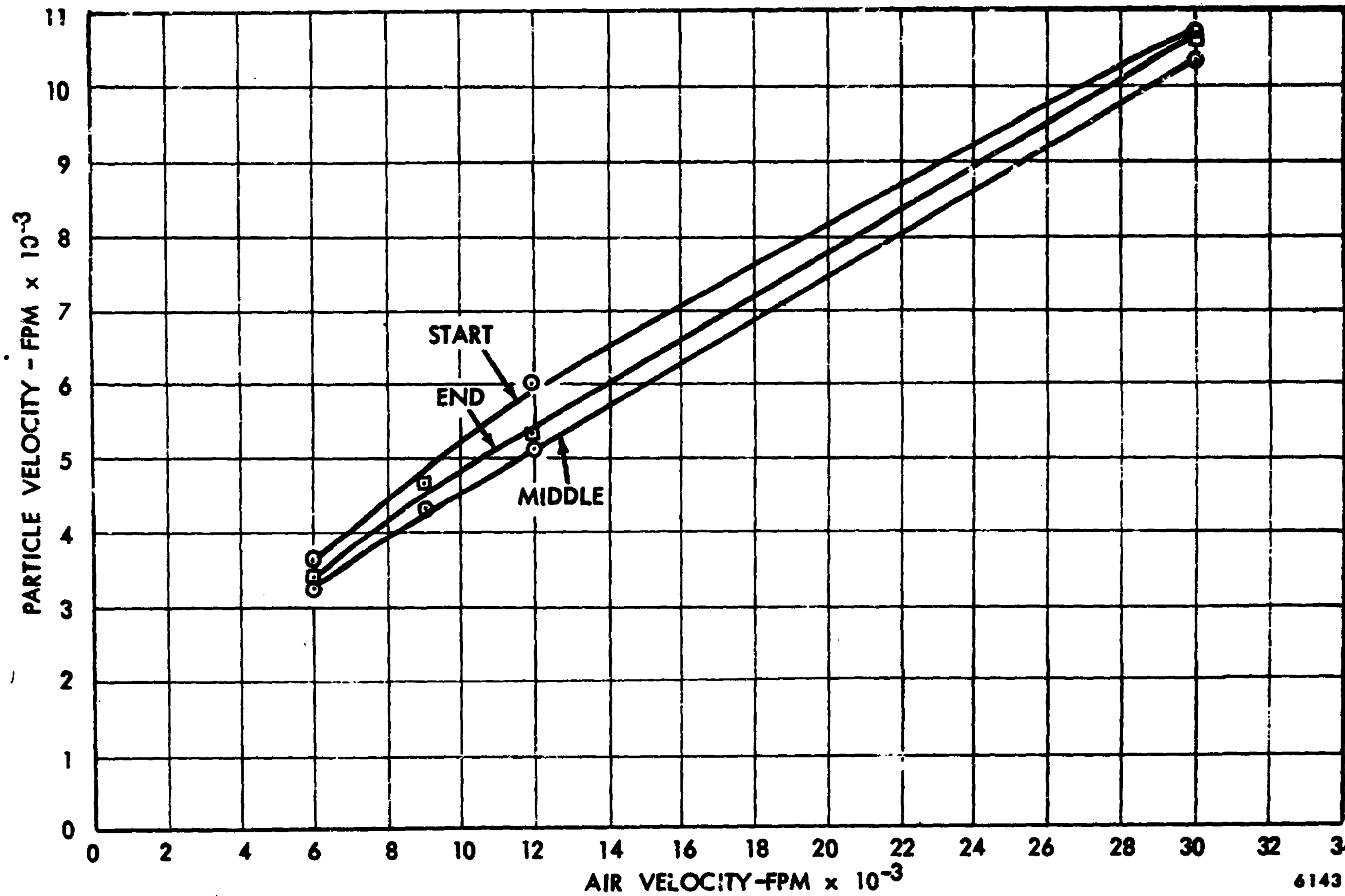


FIGURE 5
Variation in Particle Velocity During Run
(3/4-Inch-Diameter Tube and 0.135-Inch Dummy Powder. Velocity Measured 16.5 Feet from Inlet)

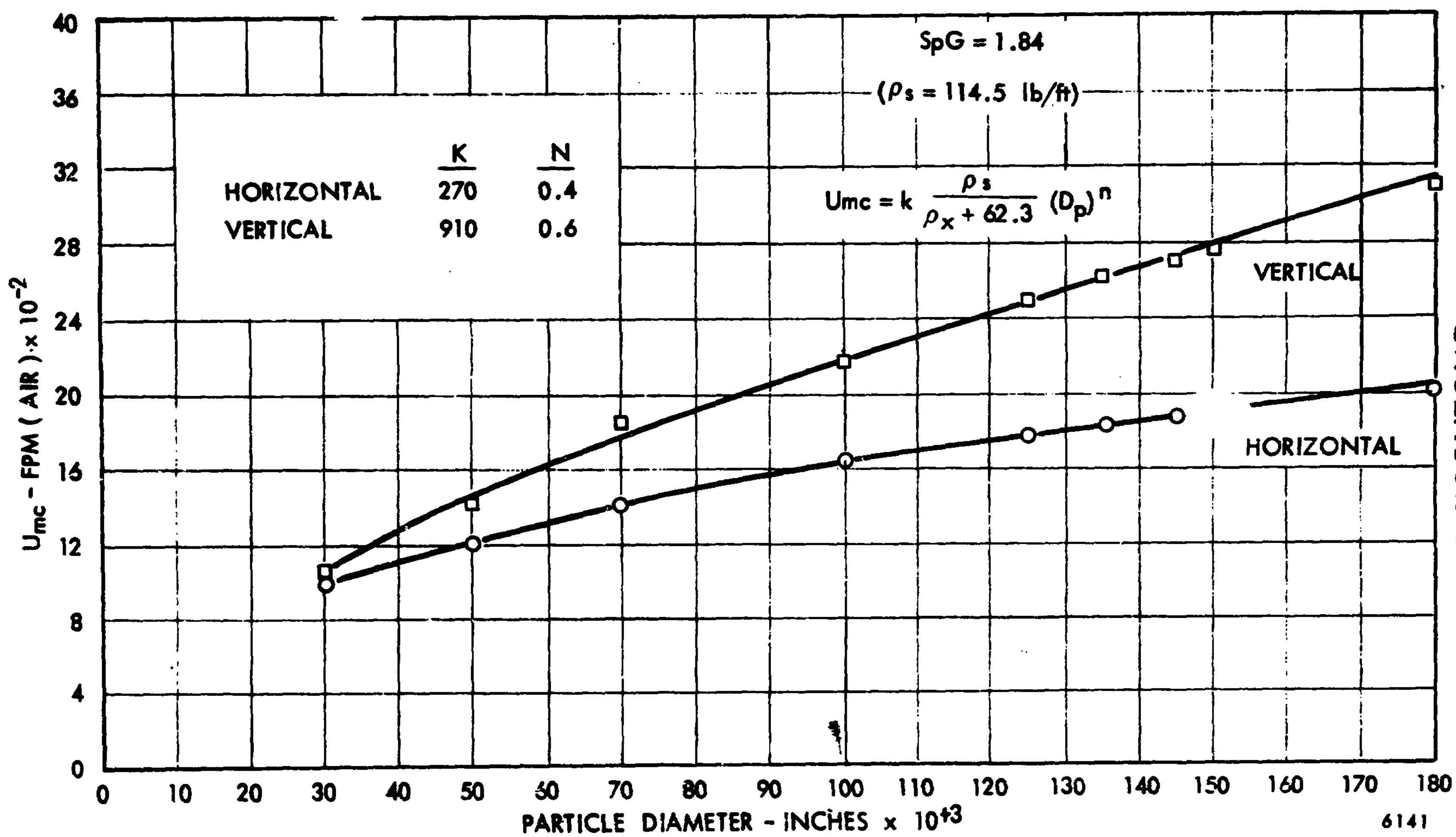
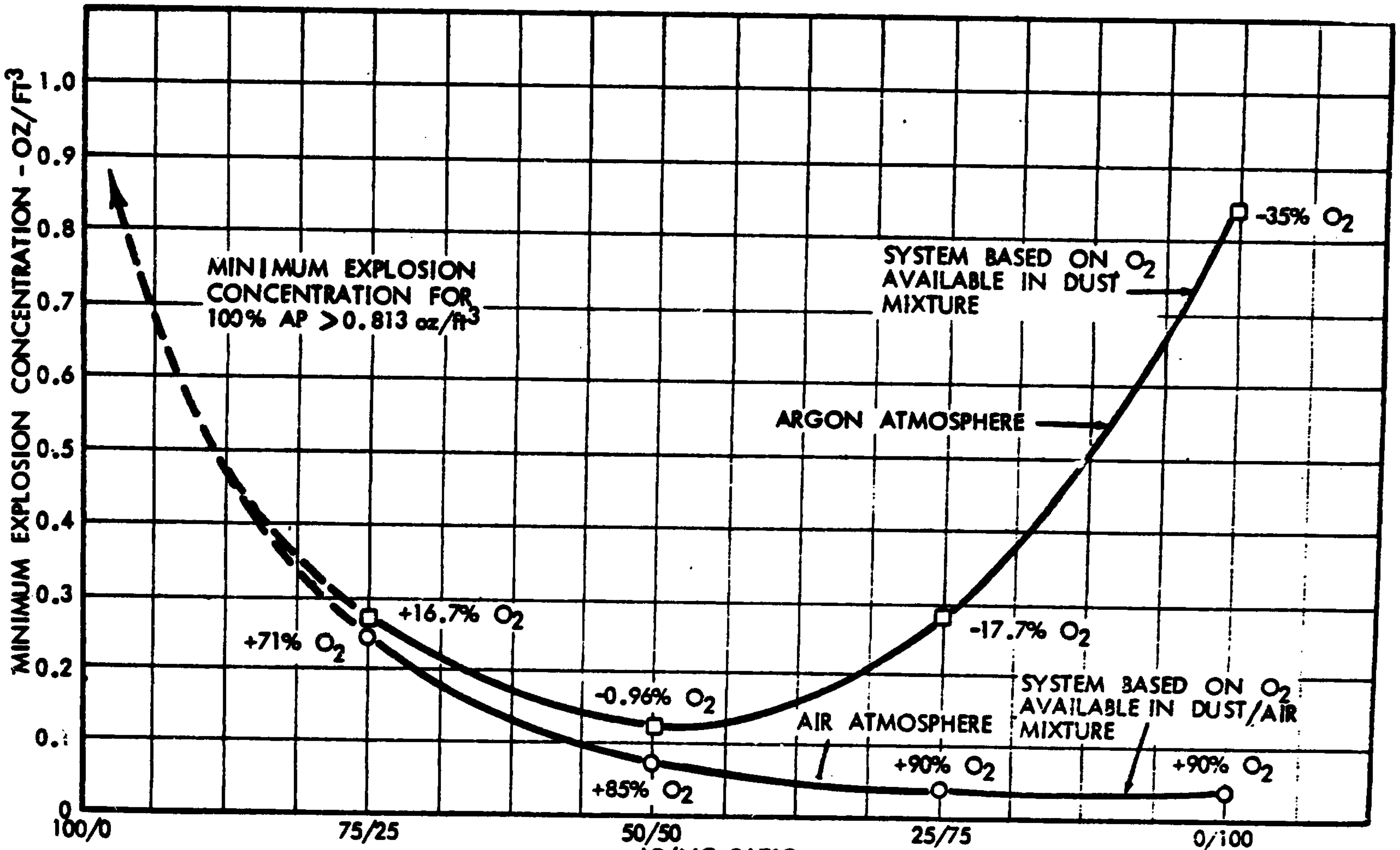


FIGURE 6
Theoretical Threshold Particle Movement Velocity



AP/NC RATIO

6784

FIGURE 7

Minimum Concentration of NC/AP Mixtures for Explosion in Air and Argon Atmospheres

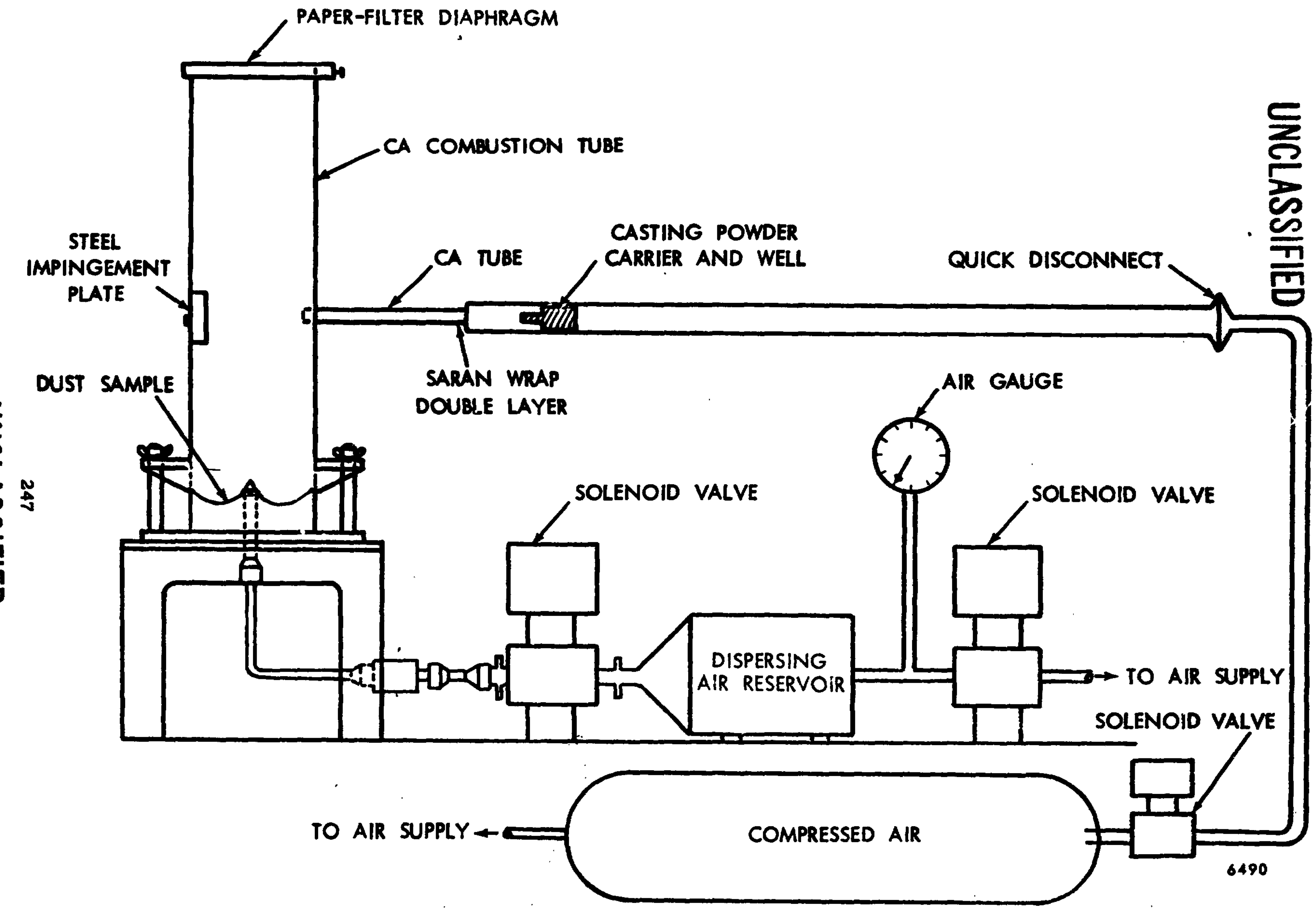


FIGURE 8
Dust Explosion and Impingement Test Apparatus

Open

Closed

G-1169

FIGURE 9
ABL-Designed "Fail-Safe" Control Valve

TNT EQUIVALENCIES

Mr. J. E. Settles
Hercules Powder Company
Wilmington, Delaware

I have asked permission to intrude upon the question and answer period for Mr. Heere's paper to take your minds back to some rather important considerations in yesterday afternoon's program. If you have questions relative to Mr. Heere's paper, we certainly want to answer them. Don't hesitate to contact us with your questions, either after this meeting, call us by telephone, or write us a letter.

Yesterday's presentation on Project "SOPHY" by Major Geisler and Mr. Richey's presentation on solid propellant hazards tests prompted a number of questions about TNT equivalency and apparently resulted in almost universal surprise that the Class 7 propellant involved in these tests gave 144 per cent TNT equivalency.

Hercules Powder Company was the manufacturer of the Class 7 motors which were involved in these tests. These were motors which were rejected during our manufacturing processes at our Salt Lake City plant. At one time, action was under way to destroy these motors by burning them in the desert at Wendover Air Force Base. With the thought in mind that it might be possible to derive appreciable value by performing hazards evaluation on these motors, I contacted Colonel McCants of the ASESB and offered to try to get the units diverted to ASESB. After quite a tussle with red tape, we succeeded; and these were the motors that were involved in the tests covered by Mr. Richey's presentation yesterday.

Colonel McCants has given me the opportunity of reviewing a draft copy of the report which the ASESB is intending to release on the portion of the tests that have been completed to date. I requested permission to make reference to these comments in this meeting, just to keep our perspective clear on this matter. I feel a major contribution to this clarity can be made by taking excerpts from the "Discussion of Results" section that is contained in the tentative copy of the ASESB report.

An important part of that report was the following:

"Table 11 (in the discussion) summarizes TNT equivalency yields from the tests conducted. Six different yield values are identified for each motor test, representing three different approaches to yield determination. It is not considered that all columns of values are equally valid. The multiple listing of values does serve to illustrate the variation that can result when: (1) different choices of gauge distance ranges are used; (2) different calibration standards are

chosen; (3) different blast characteristics are considered (e.g., impulse or overpressure)."

I have added the following three variables from my own knowledge and analysis: (4) different levels of initiation energy are used; (5) different masses of acceptor level are involved; and (6) different degrees of confinement are used. The ASBSB report also says: "The multiplicity of values also illustrates the difficulty of making an arbitrary choice of a single value of TNT equivalency for any of the tests."

Some observations based on the above variables are as follows:

Quoting from the ASBSB report, "Only two tests, number three and number four, were essentially identical; however, they did not produce identical results."

I would like to inject my personal analysis of this statement. When overpressures were derived according to methods in BRL Report No. 1518, the 14,600 pounds of propellant involved in Test 3 acted like 22,900 pounds of TNT. When this same quantity of propellant, 14,600 pounds, was tested in an identical manner in Test No. 4, it gave results equivalent to 18,400 pounds of TNT. When overpressures were determined by averaging all gauges, the 14,600 pounds of propellant in Test 3 gave results equivalent to 17,000 pounds of TNT. When 14,600 pounds of propellant was tested in an identical manner in Test No. 4, it gave results equivalent to 15,500 pounds of TNT.

The ASBSB report goes on to say, "Tests 4, 5, and 7 used identical motor combinations but different in ways previously noted. The results are similar despite the differences in test conditions.

"Tests No. 1 and No. 6 used only Class 2 motors, with twice as much propellant in No. 6 as compared with No. 1; however, there is a substantial increase in percentages in going from Test No. 1 to Test No. 6. This suggests the added mass or the disposition of the mass and relative positioning of priming charge influenced the increase."

The following comments about the tests, I believe, are in order: The derived percentage values of high explosive equivalency represent a convenient expression of potential blast damage effects in terms of common explosives; however, it is notable that there are differences in structure and rate of decay of blast waves produced by different explosives and propellants so that expressions of high explosive equivalence are limited to a generalized meaning unless there is specific identification of quantities, distances, and type of energy measured and the environment surrounding the tests.

Additionally it should be noted that in the ASESB tests the measurements made and the methods of analysis employed required the cubing of a derived $W^{1/3}$ value to arrive at the W values which are presented in Tables 11 and 12 of the report, so that errors in measurement or possible real anomalies in the blast wave are amplified in the expression W.

Yesterday Mr. Bishoff pointed out during the discussion of the tests at NOTS that if a propellant actually does give 144 per cent TNT equivalency then we must be deeply concerned about the need for possible modification of published quantity-distance tables. I agree wholeheartedly with the point raised by Mr. Bishoff. I will say that the 144 per cent equivalency figure was a surprise to us. We had anticipated that equivalency figure would be 120 to 125 per cent and some time ago computed the results in blast overpressures and assessed the potential effects on quantity-distance tables should this level of TNT equivalency be superimposed on our plant structures and buildings. At that time, it was our conclusion that no modification of existing QD tables needed to be made. Last night, I recomputed the overpressure values for propellant that would give 144 per cent TNT equivalency. Here are the results of my study.

The Class 7 motors involved in the test weighed 7,350 pounds. If propellant of that weight yielded 144 per cent TNT equivalency, it would produce blast pressures equivalent to 10,600 pounds of TNT. At a 200 foot distance from the site of a detonation of 7,350 pounds of explosives, the blast overpressure will be approximately 9 psi. At this same distance from a detonation of 10,600 pounds of explosives, the blast overpressure will be approximately 10.5 psi. I chose the 200 foot distance because it is approximately the intraline distance required by QD tables for 7,350 pounds of explosives.

At this point, I would like to inject this fact. I started in this business over 22 years ago; and during this period of time, I have had an opportunity to visit numerous sites of explosions both in this country and in foreign countries. On several occasions, I have taken missile maps and scribed blast overpressure radii at various distances, such as a 10 psi radius, 15, 20, 25, 50, and 100 psi radii. In several cases I have found buildings at the 10 psi radius suffered greater damage than buildings closer in at the 15 psi radius.

However, in my overpressure computations last night, the next radius I evaluated was at 500 feet. At this distance a 7,350 pound unit will give approximately 2.6 psi overpressure; a 10,600 pound unit will give approximately 3 psi overpressure.

At a radius of 1,000 feet, a 7,350 pound unit will give an overpressure of about .82 psi; a 10,600 pound unit will give an overpressure of approximately 1.0 psi.

At a distance of 1,340 feet, which is approximately inhabited building distance for the quantity, the blast overpressure for a 7,350 unit will be approximately .55 psi; for a 10,600 unit, it will be approximately .6 psi.

At a radius of 1,500 feet, a 7,350 pound unit will yield an overpressure of approximately .48 psi; a 10,600 pound unit will yield an overpressure of approximately .58 psi.

These results indicate to me that any major change in quantity-distance tables for this value of TNT equivalence is not required and that it would not be very meaningful or realistic if we were to attempt it.

I would like to say that we at Hercules Powder Company are very interested in having our safety parameter set in realistic aspects. We have been much interested in this for quite some time and we will continue to be. I think the recent revisions which the ASESB made to our quantity-distance table, the one which reduced the number of hazard classes from 12 to 8, was a real advance in realism. I understand that sometime this fall revisions to the hazard classification procedures will be published. This, too, is going to be a very important contribution to improving the realism that exists in our safety effort. I would also like to say that I'm sure that this particular seminar, as we go on down through the years, is going to be a real claringhouse for these improvements in realism in our safety efforts.

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SAFETY ASPECTS OF SOLID PROPELLANTS IN THE SATURN FACILITIES

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NASA
Cocoa Beach, Fla.

PROBLEM: To devise the most efficient assembly and check-out procedure for the SATURN V "Moon Rocket." SATURN V consists of three stages: S-IC, S-11, S-IVB.

Total height w/o spacecraft		282 feet
	w/Apollo spacecraft (82')	364 feet
Weight of entire vehicle - 3 stages, IU, Spacecraft		
	Dry	500,000 lbs.
	At ground ignition	6,102,000 lbs.
Total fuel weight		5,560,000 lbs.

Some idea of complexity can be gained from the following: Number of persons involved in checkout and assembly, approximately 3,300 to 3,500 (VAB, Pad and LCC). Number of days checkout, etc. 98 (68 VAB - 30 pad). This operation has required the development of several new concepts of assembly checkout, etc. Some of these are as follows:

1. Vehicle transport modes - Many transport modes and systems were carefully evaluated, most feasible were considered to be barge, crawler and rail, and the independent crawler-transporter. Conclusions were that the independent crawler-transporter would be more feasible.

2. Vehicle Assembly Building - Unique in that it is the largest building in the world by volume - 129,500,000 cu. ft., overall length 716 ft.; overall width 518 ft.; overall height 526 ft.; air-conditioning 10,000 tons, etc.

3. Automatic Checkout Procedures - the assembly of the launch vehicle on the mobile launcher in the VAB has an advantage over present concepts in that umbilical connections will remain intact while the vehicle is being transported to the pad; thereby preserving the validity of tests made in the assembly building. An interconnecting cable carrying digitized information and commands will be the only connection between the Launch Control Center and the space vehicle on the pad.

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SPACE VEHICLES

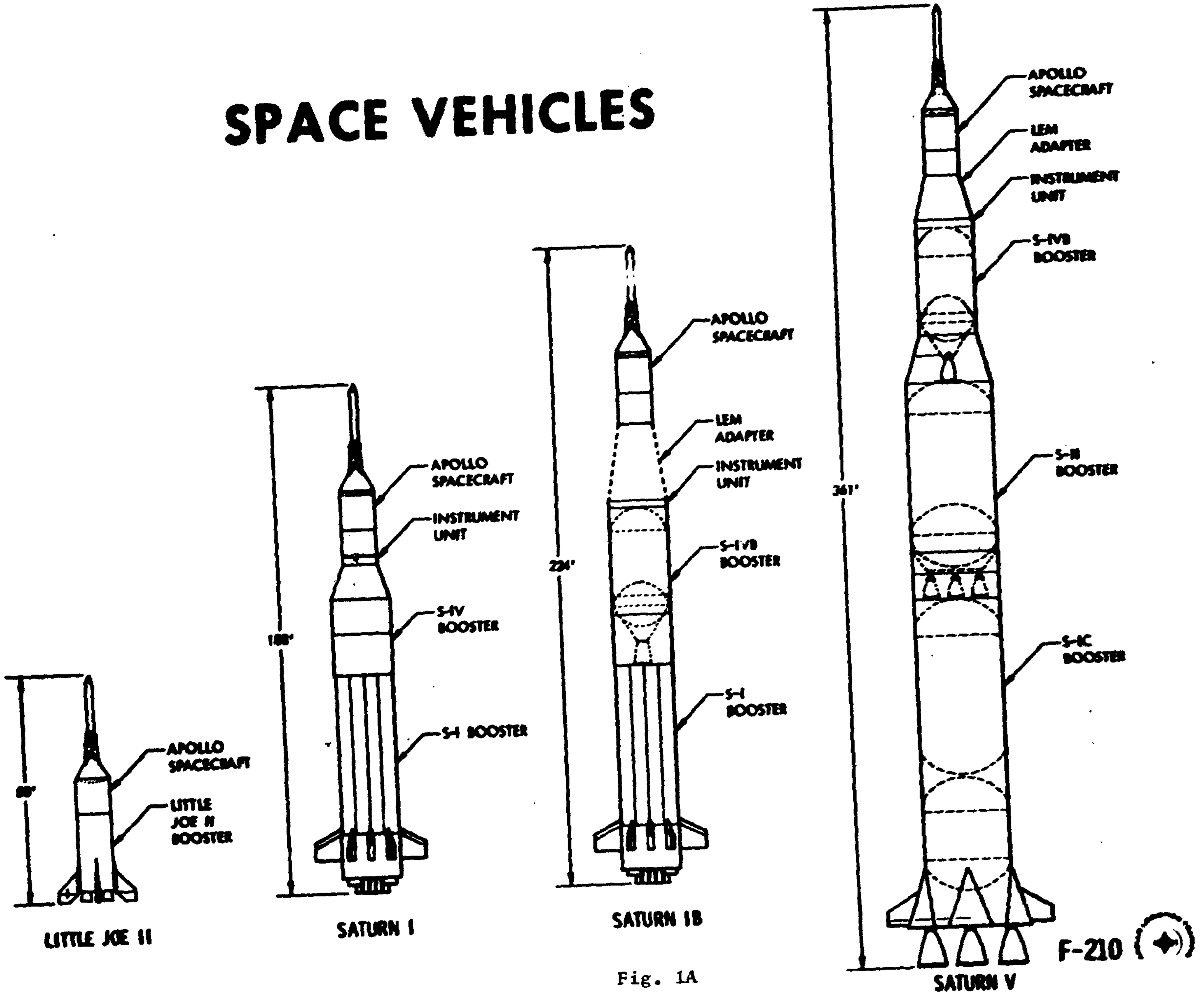

Fig. 1A

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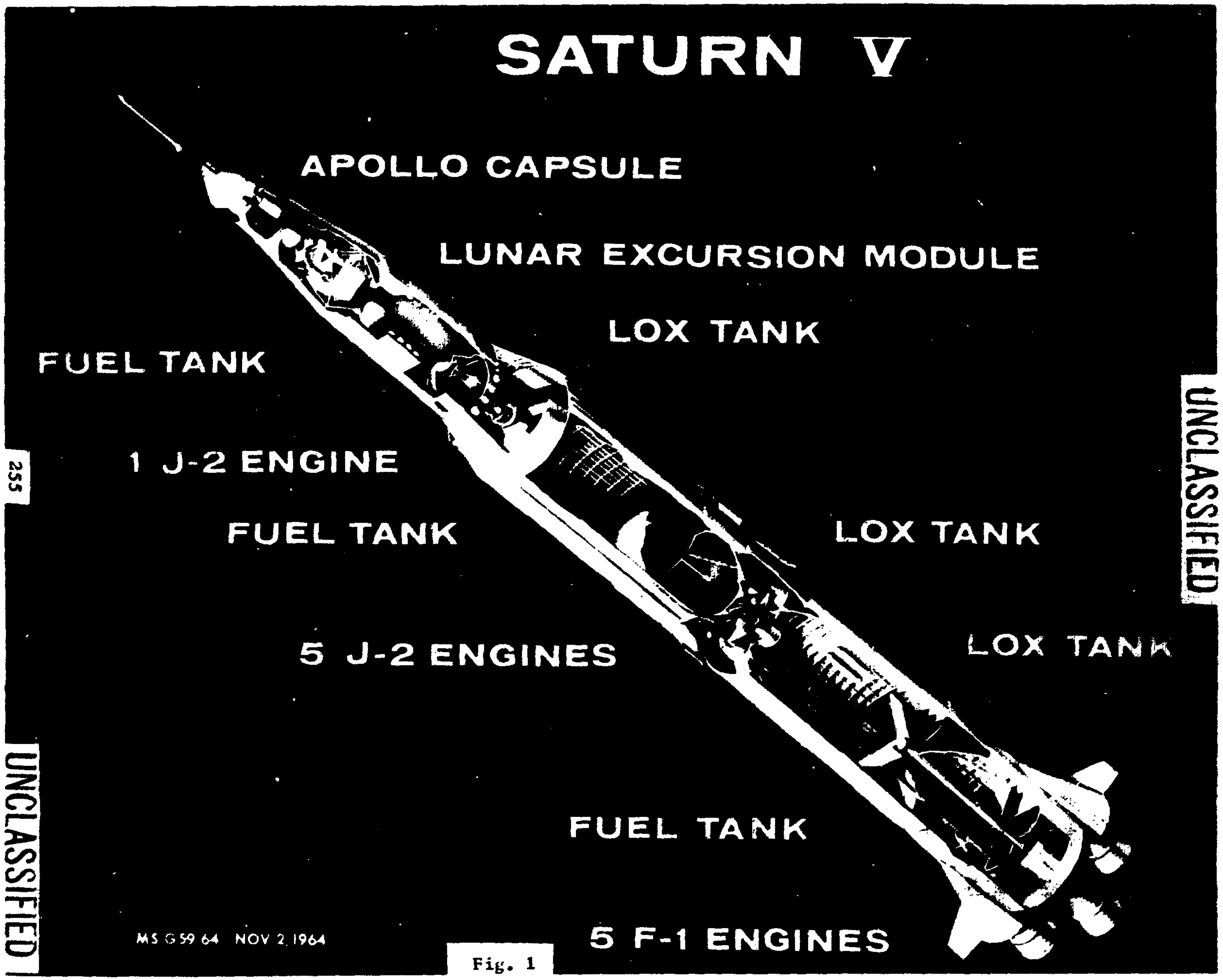

Fig. 1

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This suggests another important advantage - the reduction of operational work time. The disconnection and reconnection of components, the principal reason checkout procedures are now repeated at the launch site, will no longer be necessary. This will also reduce launch preparation costs.

At present much of the checkout and launch equipment is composed of analog computers whose findings are affected by the voltage drops encountered over long distances. This has contributed to the requirement for a blockhouse in the immediate vicinity of the pad. With digital computers, which record by impulse, variable voltage is not a factor; therefore, data received from a long distance remains valid. In addition to eliminating the need for a blockhouse, it is now possible to checkout and launch the space vehicle with one set of equipment located in the Launch Control Center.

I might add, in passing, that all these factors required new philosophy on the part of safety personnel.

Adding to our problem the SATURN V spacecraft combination contains 98 different explosive devices; 858 explosives ordnance items and retro and ullage rockets, including those on the spacecraft.

Our original plan was as follows:

1. Stage build-up in VAB.

2. Transport to arming tower for ordnance installation, including LES (arming tower positioned approximately 6,000 ft. from Pad A).

3. Move to pad for launch.

4. Principal advantages - installation of ordnance in a comparatively remote area. (NOTE: At this time, design concepts for ullage and retro rockets was not finalized, and it was assumed from our information that some Class 7 propellants might be used).

5. Principal disadvantages were:

a. Extended exposure time in unprotected environment.

b. Final design concepts of destruct and separation charges made it virtually impossible to install these from arming tower as designed.

<u>GENERAL DESCRIPTION</u>:

The following will acquaint you with the SATURN V program:

Fig. 1B Artist Concept of KSC Area

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SATURN V

Vehicle

Number of Stages--------------------------------3

Length
Without Apollo Spacecraft--------------------282 ft.
With Apollo Spacecraft----------------------364 ft.

Weight - 3 Stages, IV, Spacecraft
Dry--500,000 lbs.
At Ground Ignition--------------------------6,102,000 lbs.

S-1C STAGE

Prime Contractor-------------------------------Boeing

Length---138 ft.

Diameter
Within Fins----------------------------------- 33 ft.
With Fins------------------------------------- 63 ft.

Weight
Dry--287,000 lbs.
At Ground Ignition---------------------------4,700,000 lbs.

Engines--5 (Rocketdyne F-1)

Total Thrust-----------------------------------7.5×10^6

Propellants------------------------------------LOX/R-P1

Propellant Capacity---------------------------- 4,400,000 lbs.
LOX-- 340,000 gal.
RP-1--- 205,000 gal.

Mixture Ratio (WO/WF)-------------------------2.25 - 1

S-11 STAGE

Prime Contractor------------------------------North American

Length--81 ft 6 in

Diameter--------------------------------------33 ft

Weight
  Dry-- 75,000 lbs.
  At Ground Ignition-------------------------1,000,000 lbs.

Engines---------------------------------------5 (Rocketdyne J-2)

Total Nominal Thrust--------------------------1,000,000 lbs (Vacuum)

Propellants-----------------------------------LOX/LH_2

Propellant Capacity---------------------------930,000 lbs.
  LOX-- 82,700 gal.
  LH_2---------------------------------------263,000 gal.

Mixture Ratio (WO/WF)-------------------------5:1

S-IVB STAGE

Prime Contractor------------------------------Douglas

Length--58 ft 8 in

Diameter (Forward of Interstage)--------------21 ft 8 in

Weight
  Dry-- 21,900 lbs.
  At Ground Ignition-------------------------262,000 lbs.

Engine--Rocketdyne J-2

Total Nominal Thrust--------------------------200,000 lbs (Vacuum)

Propellants-----------------------------------LOX/LH_2

Propellant Capacity---------------------------230,000 lbs.
  LOX-- 20,262 gal.
  LH_2-- 72,860 gal.

Mixture Ratio (WO/WF)------------------------ 5:1

MOBILE LAUNCHER

Type	Open steel structure on launch platform
Height	445 ft 9 in
Weight	10,600,000 lbs.
Launch Platform: Width	135 ft.
Length	160 ft.
Platforms	17
Elevators	2
Capacity (each)	2500 lbs.
Speed	600 FPM maximum
Crane	1 Hammerhead
Capacity - 50 ft. from Swivel	25 tons
85 ft. from Swivel	10 tons
Swing Arms	9
S-IC Stage	2
S-II Stage	3
S-IVB Stage	2 (includes IU)
Spacecraft	2

CRAWLER-TRANSPORTER

Height
  Minimum (cylinders retracted)----------------20 ft.
  Maximum (cylinders extended)-----------------26 ft.

Length---131 ft.
Width--114 ft.
Weight---5,500,000 lbs.

Speed
  Loaded---------------------------------------1 MPH maximum
  Unloaded-------------------------------------2 MPH maximum

Load Capacity----------------------------------12,000,000 lbs.

Power System (DC)------------------------------Powers 16 traction motors
  Diesel Engines-------------------------------2
  Horsepower-----------------------------------2750 ea.
  Generators-----------------------------------4
  Power Output---------------------------------1000 KW ea

Generators (2)---------------------------------Power Output 750 KW ea

Power Systems (AC)-----------------------------Powers leveling, jacking steering lighting, ventilating electronic gear.

Diesel Engines (2)-----------------------------Horsepower 1065 ea

VEHICLE ASSEMBLY BUILDING

Overall Length	716 ft.
Overall Width	518 ft.
Height------(Top of finished roof)	526 ft.
Volume	129,500,000 cubic ft.
Low Bay	
Length	275 ft.
Width	442 ft.
Checkout cells	8
High Bay	
Length	442 ft.
Width	518 ft.
Height	526 ft.
Bays	4 (2 equipped initially)
Elevators	
To floor 34	16 (462 ft. levels)
Floor 34 to roof	1
Extensible Platforms	10 in ea bay, 5 ea side
Entrance Levels	Floors 10, 14, 20, 25, & 28

CRAWLERWAY

Type	Dual roadway, spaced on 90 foot centers
Main Roadway Area	2 divided lanes
Lane Width	40 ft.
Overall Width	130 ft.
Design Load	65 psi
Length from VAB	
To Crawler Parking Area	1200 ft.
To Mobile Service Structure	12,000 ft.
To Launch Pad A	18,000 ft.
To Launch Pad B	25,000 ft.

MOBILE SERVICE STRUCTURE

Type Construction-----------------------Steel truss
Height
  Aboveground level----------------------402 ft.
  Above LUT deck-------------------------353 ft.

Platforms 5
  Self-propelled--------------------------2 - Nos. 1 & 2
  Access capability-----------------------No. 1 to serve S-1C, S-11 & S-11/S-IVB interstage
  No. 2 to serve S-11/S-IVB interstage, S-IVB & I.U.
Fixed relocatable-------------------------3 -- Nos. 3,4 & 5
  No. 3-----------------------------------Enclosed, with ECS for LEM
  No. 4-----------------------------------Enclosed, with ECS for CM & SM
  No. 5-----------------------------------Open with chain link fence for LES

Operational winds--------------------------63 mph, free standing
85 mph, pad position w/holddown clamps
125 mph, park position w/holddown clamps

LAUNCH PADS

Shape---------------------------------------8 sided polygon

Distance Across-----------------------------3,000 ft.

Hardstand Size------------------------------390 x 325 ft.

Elevation (at center)-----------------------48 ft. above sea level

RP-1 System
  Distance from Pad-------------------------1,350 ft.
  Number of Tanks---------------------------3
  Capacity----------------------------------86,000 gal. per tank
  Fluid Weight------------------------------1,730,000 lbs.

LOX System
  Distance from Pad-------------------------1,450 ft.
  Tank Capacity-----------------------------900,000 gal.
  Fluid Weight------------------------------8,600,000 lbs.
  Boil-off Rate-----------------------------0.18% per day max.
LH_2 System
  Distance from pad-------------------------1,450 ft.

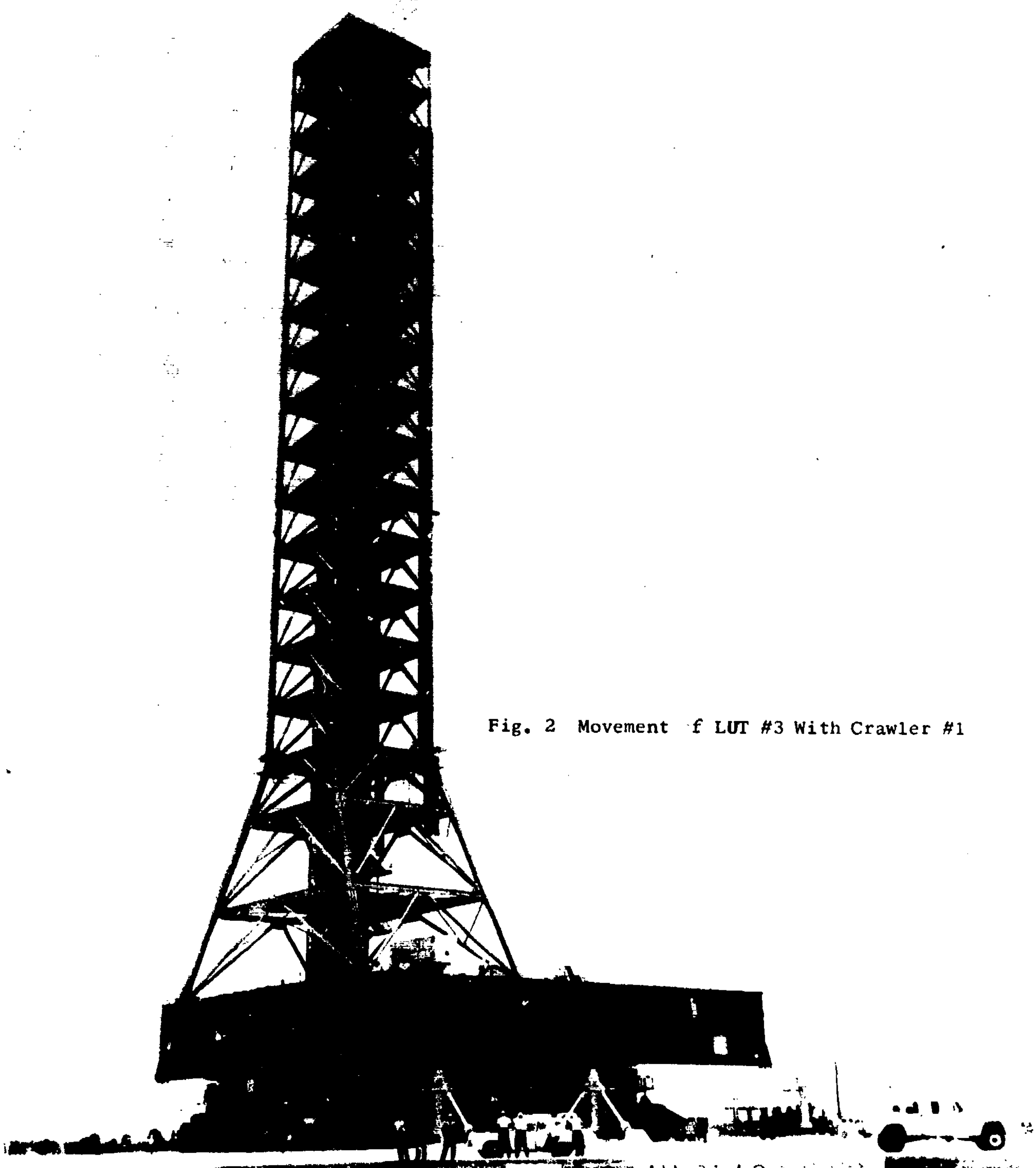

Fig. 2 Movement of LUT #3 With Crawler #1

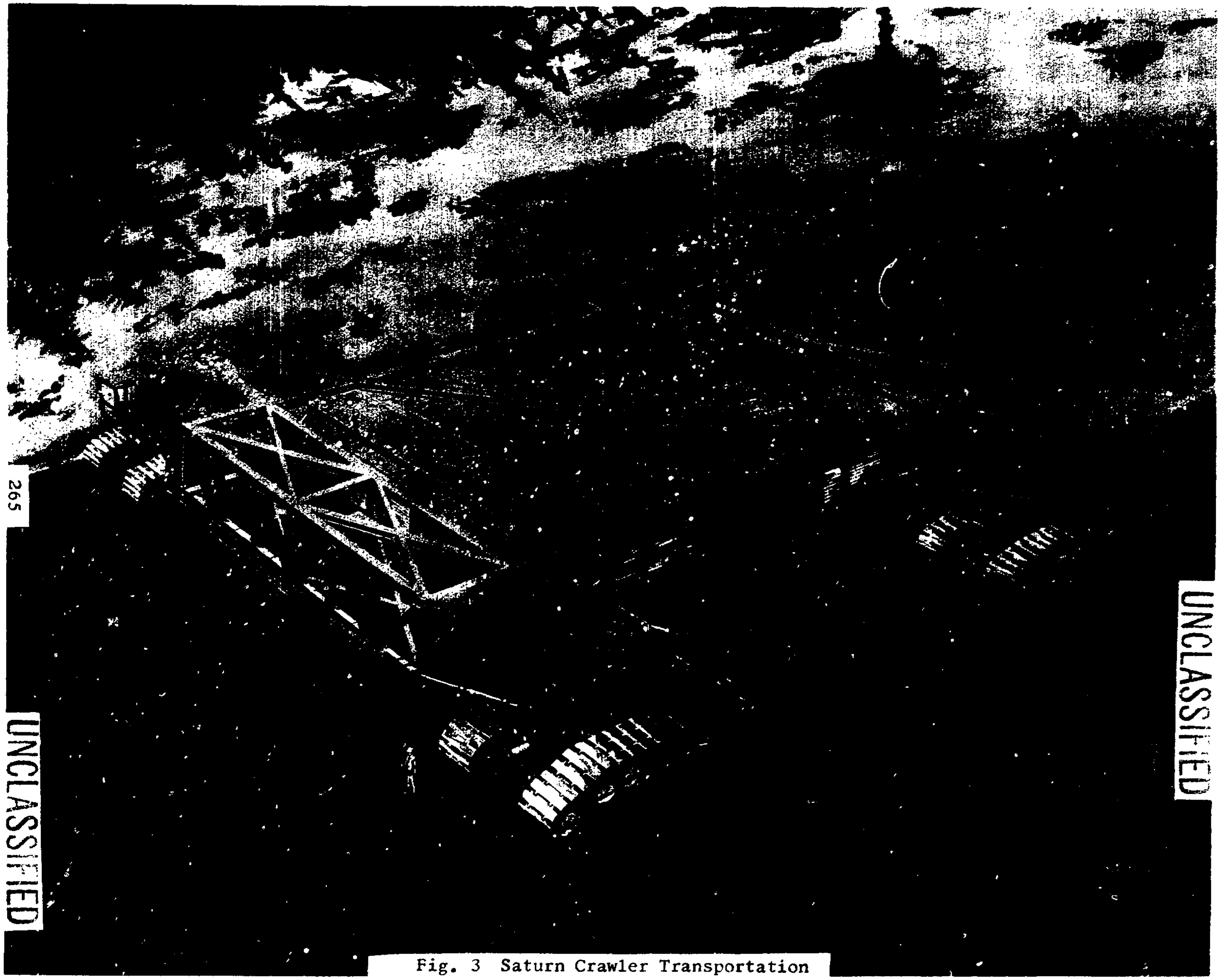

Fig. 3 Saturn Crawler Transportation

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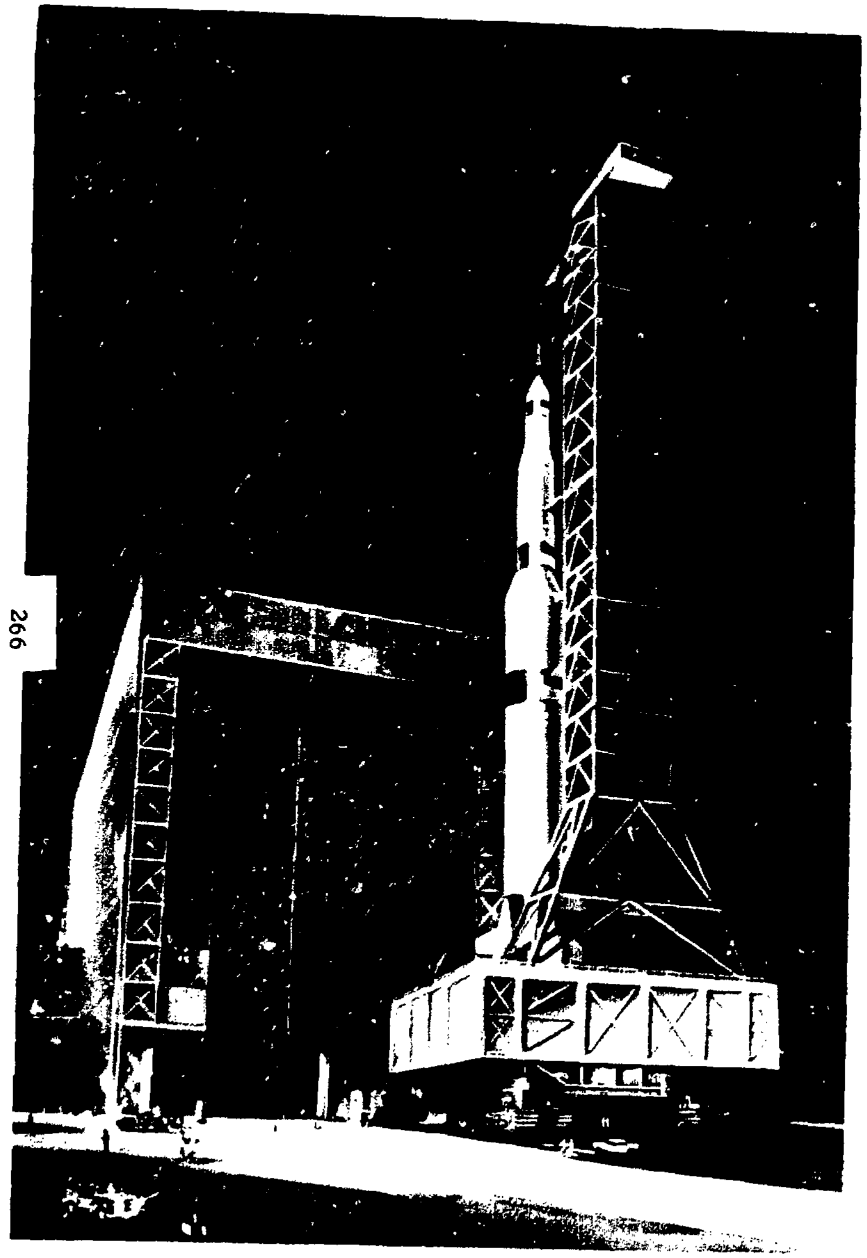

SATURN V

CRAWLER TRANSPORTER VEHICLE

LENGTH — 131 FEET
WIDTH — 114 FEET
HEIGHT — 20 FT. RETRACTED, 26 FT. EXTENDED
WEIGHT — 5,500,000 LBS
LOAD CAPACITY — 12,000,000 LBS STATIC, 16,000,000 LBS DYNAMIC
SPEED — 2 MPH MAXIMUM UNLOADED, 1 MPH LOADED
LEVELING CAPABILITY — MAINTAIN LEVEL TO 10 MIN. ON 5° GRADE
TURN RATE — 10° PER MIN. MAX
CONTRACTOR — MARION PWR SHOVEL CO, MARION, OHIO
COST — $ 4,000,000 - 5,000,000 EACH
DELIVERY SCHEDULE: 1st CRAWLER - OCT 30, 1965, 2nd CRAWLER - MARCH 30, 1966

LVO-HOUSE - NOV 19, 1964 E-D D 5000C MS-G-14-4-63 REV. C

Fig. 3A

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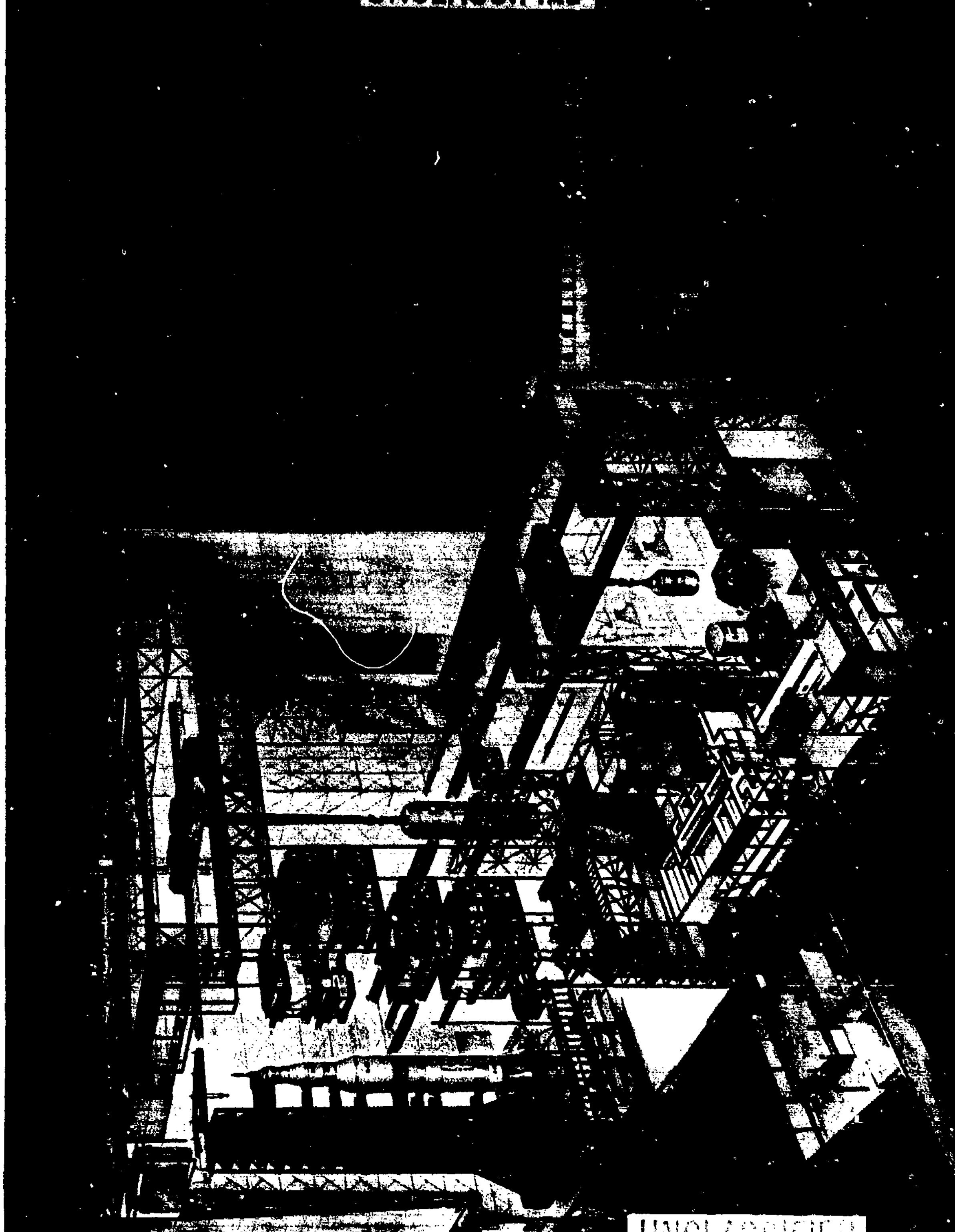

Fig. 4 Artist's Concept: Cut-a-way view of vertical assembly bldg., showing launch control center and launcher umbilical tower in background.

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Fig. 5 Aerial view of VAB with Pad 39A in background.

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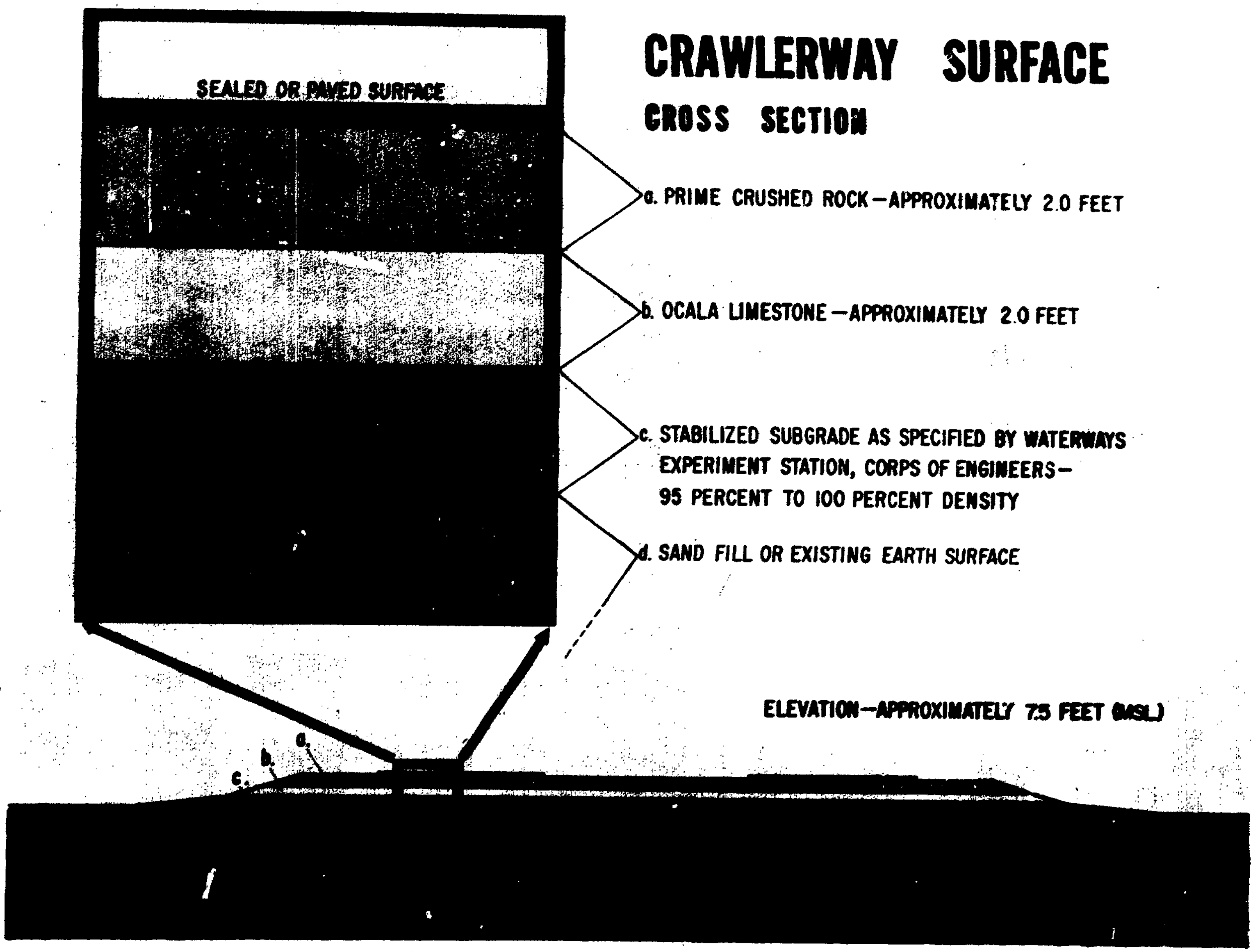

CRAWLERWAY SURFACE
CROSS SECTION
SEALED OR PAVED SURFACE
a. PRIME CRUSHED ROCK—APPROXIMATELY 2.0 FEET
b. OCALA LIMESTONE—APPROXIMATELY 2.0 FEET
c. STABILIZED SUBGRADE AS SPECIFIED BY WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS—95 PERCENT TO 100 PERCENT DENSITY
d. SAND FILL OR EXISTING EARTH SURFACE
ELEVATION—APPROXIMATELY 7.5 FEET (MSL)
a.
b.
c.

Fig. 5A

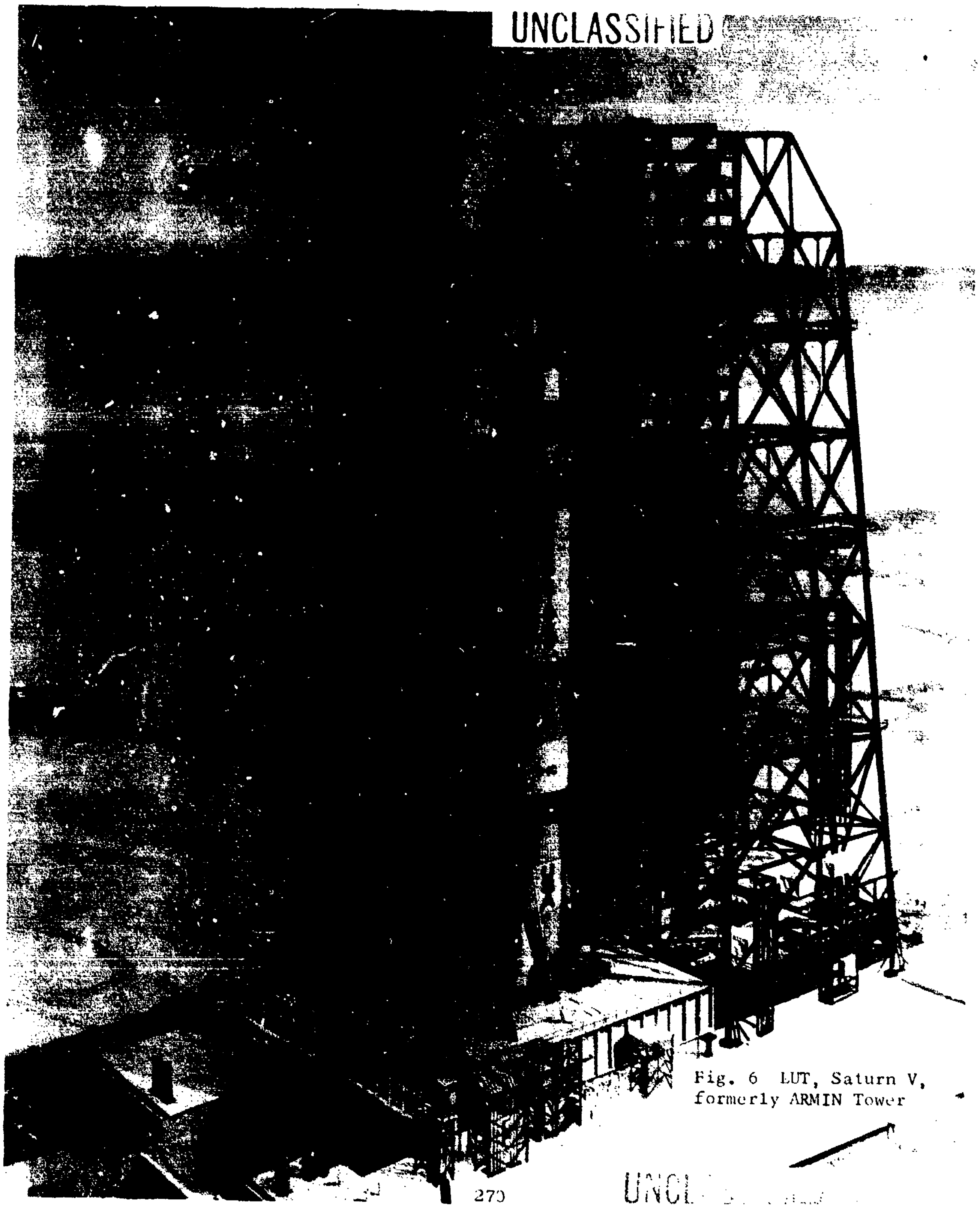

Fig. 6 LUT, Saturn V, formerly ARMIN Tower

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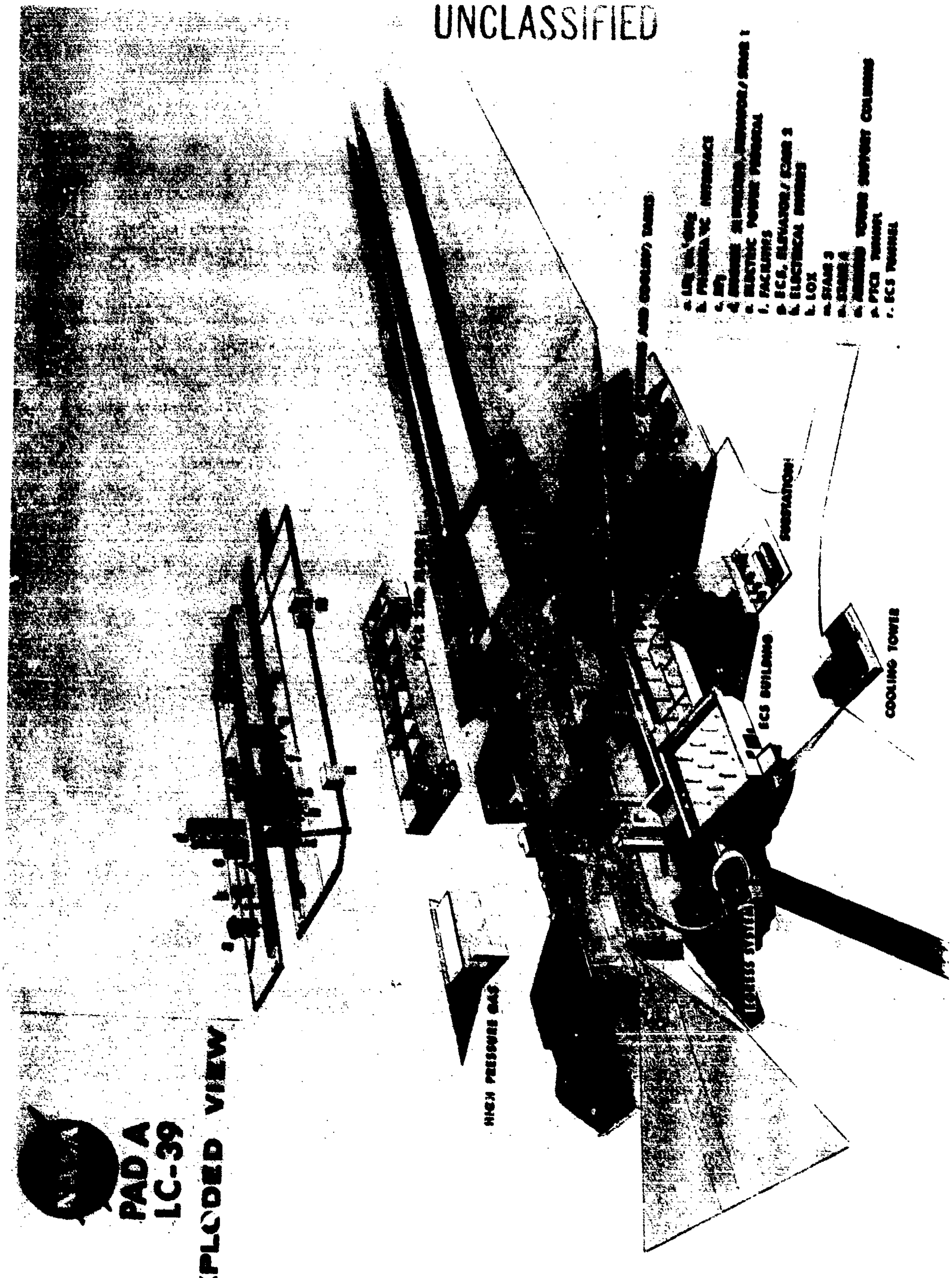

Fig. 7

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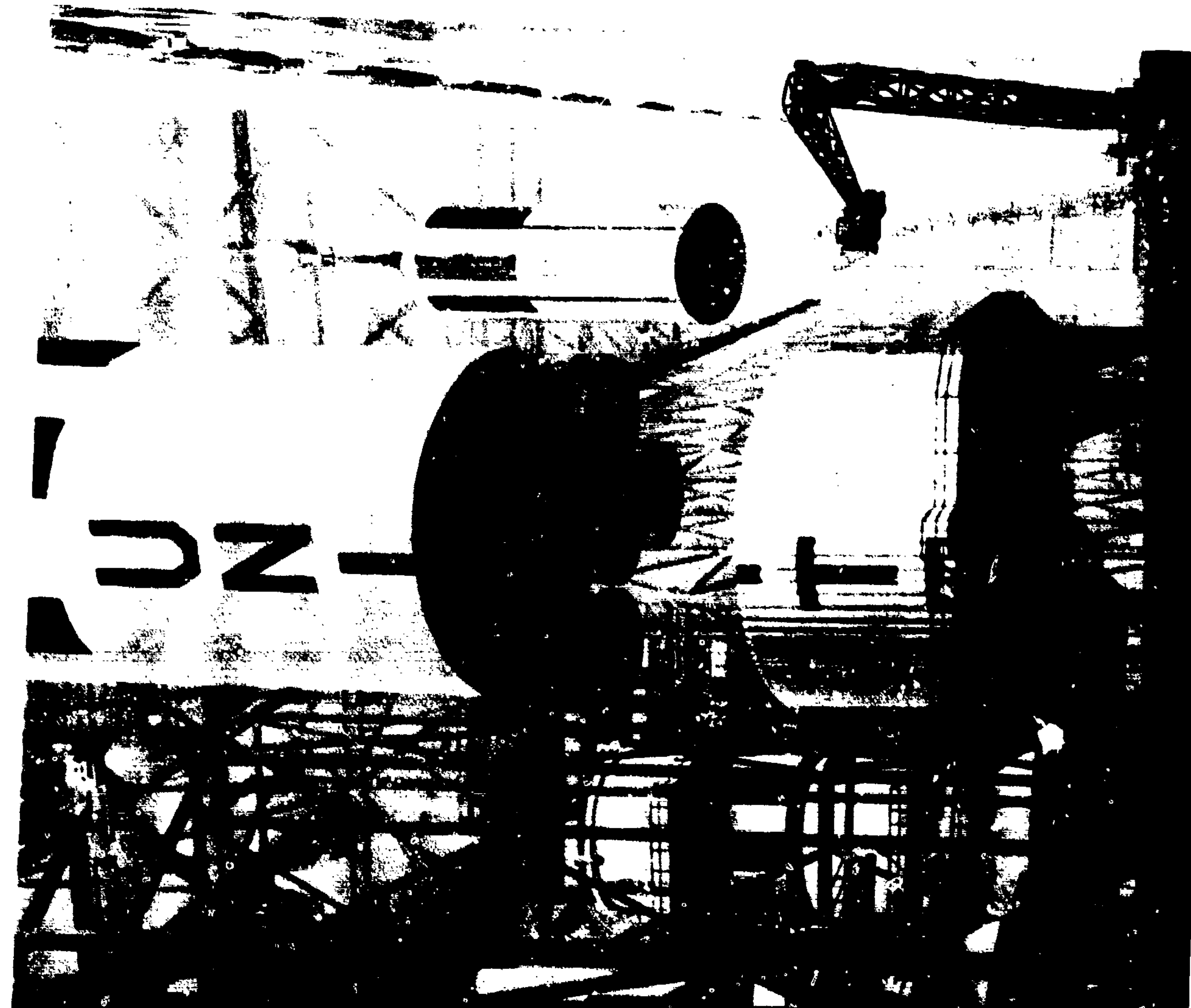

Fig. 8 Artist Conception of VAB Erection of SATURN

Initially, it was planned to deliver the booster, second and third stages and spacecraft to the Vehicle Assembly Building, where approximately 2,525 persons would work for 62 days at the process of mating, installing and checking electronic, hydraulic and other equipment, and then transport the vehicle on a gigantic crawler to a mobile service structure, midway to the launch pedestal, where the ordnance items (minus initiating devices) would be installed. Following this operation (6 days) the crawler would continue with its load to the launch site, place the vehicle, back out, pick up the MSS and position it next to the vehicle for installation of initiators and final launch preparations (including fueling, countdown, demonstration and launch).

The Mobile Service Structure serves a purpose similar to that of the gantry used in previous orbital space missions. It has five work platforms which enable technicians to service the vehicle. Each platform is intended to handle one or more of the various stages. The platforms project from the forward face of the tower and have hinged sections which swing around the body of the vehicle, giving 360° access to the surface of the vehicle. The two lower platforms are vertically self-propelled under control of operators on the platforms themselves. The upper three platforms are bolted in place at the best locations for servicing their respective stages.

The tower includes buildings for housing machinery and equipment, sanitary facilities, an operations support room and communications centers. It has elevators for reaching the various platforms, walkways for personnel, warning lights for aircraft, stairways, lighting facilities and weather-sensing instruments. It operates from the base operations electrical supply, but also had diesel-electric generators for emergency use.

INDICATIONS OF TROUBLE: An original plan called for an approximate assembly and checkout time (or launch cycle) of 7 days. However, as the moment of truth got a little closer, several significant problems developed. First, it was discovered that the installation and proper securing of the linear destruct charges would require access along every few feet of the stage requiring that the MSS be modified by addition of one or more moveable platforms to provide continuous access. This, in turn, threatened to overload the structure, necessitating redesign and still more weight and this also, in turn, would be reflected in a heavier load on the crawler, possibly to the point where ground pressure was too great. In addition, the time consumed in installing the ordnance items at the MSS, and due to the concomitant need to install dummy devices for circuit checks in the VAB, was such that launch schedule dates could not be met. Estimating the cost of delays in schedules at roughly $\$10^6$/ day, it became obvious that certain measures would have to be taken to speed up the process. It was apparent that considerable savings in time and money could be effected if it were possible to install ordnance items on the

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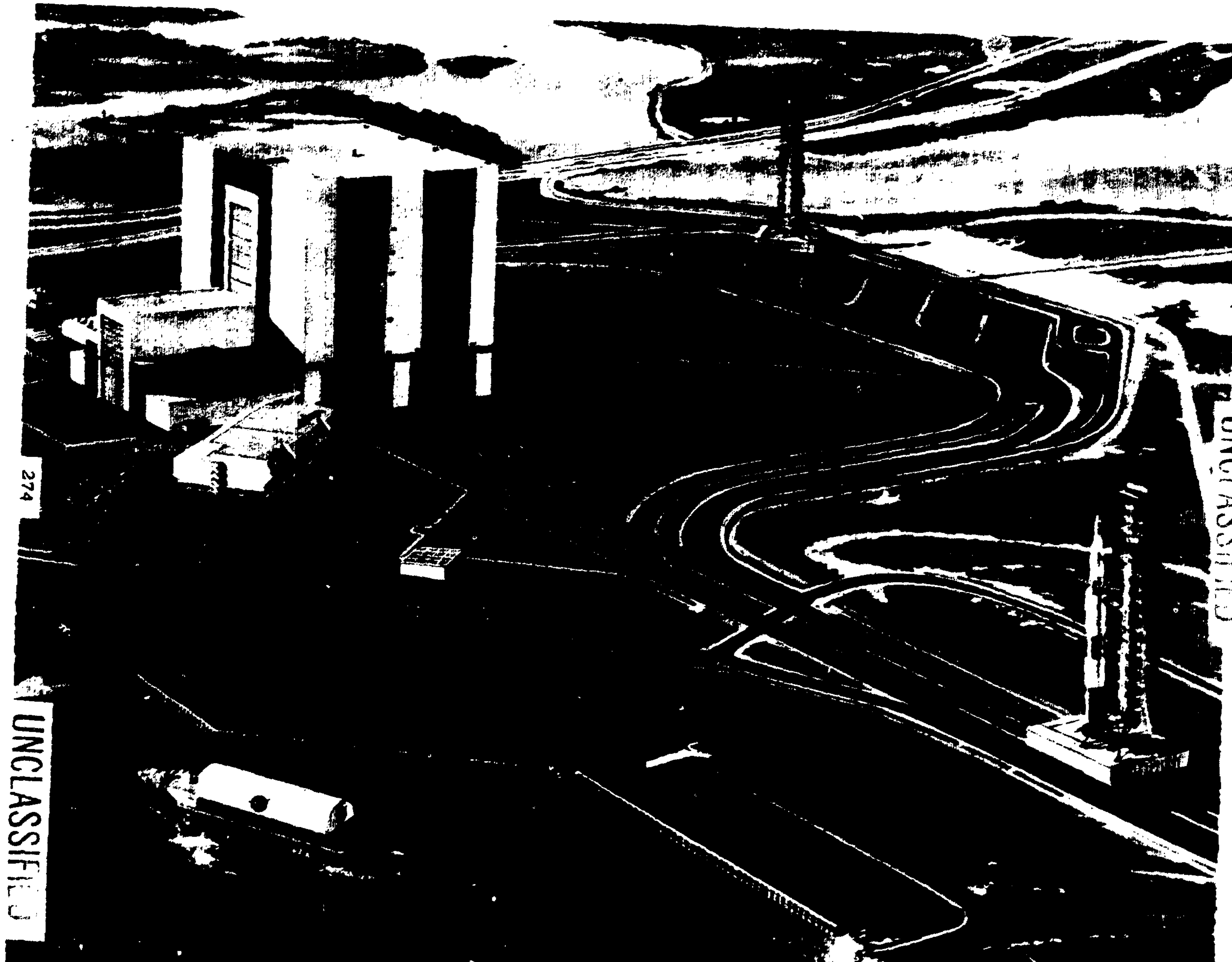

Fig. 9 Artist Drawing of VAB and LUTS, from turning basin

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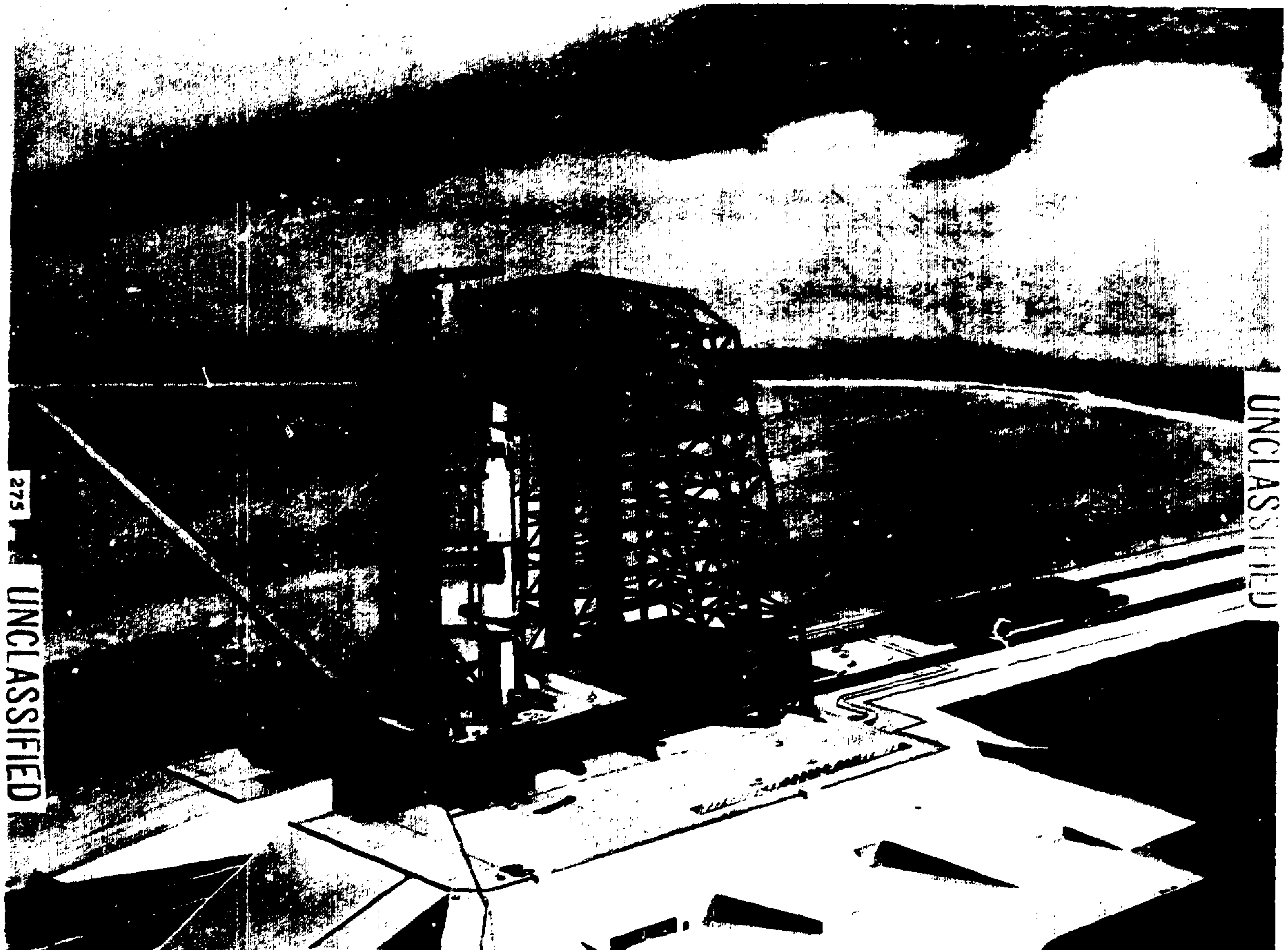

Fig. 9A Artist concept: LUT and Arming Tower with Crawler in background

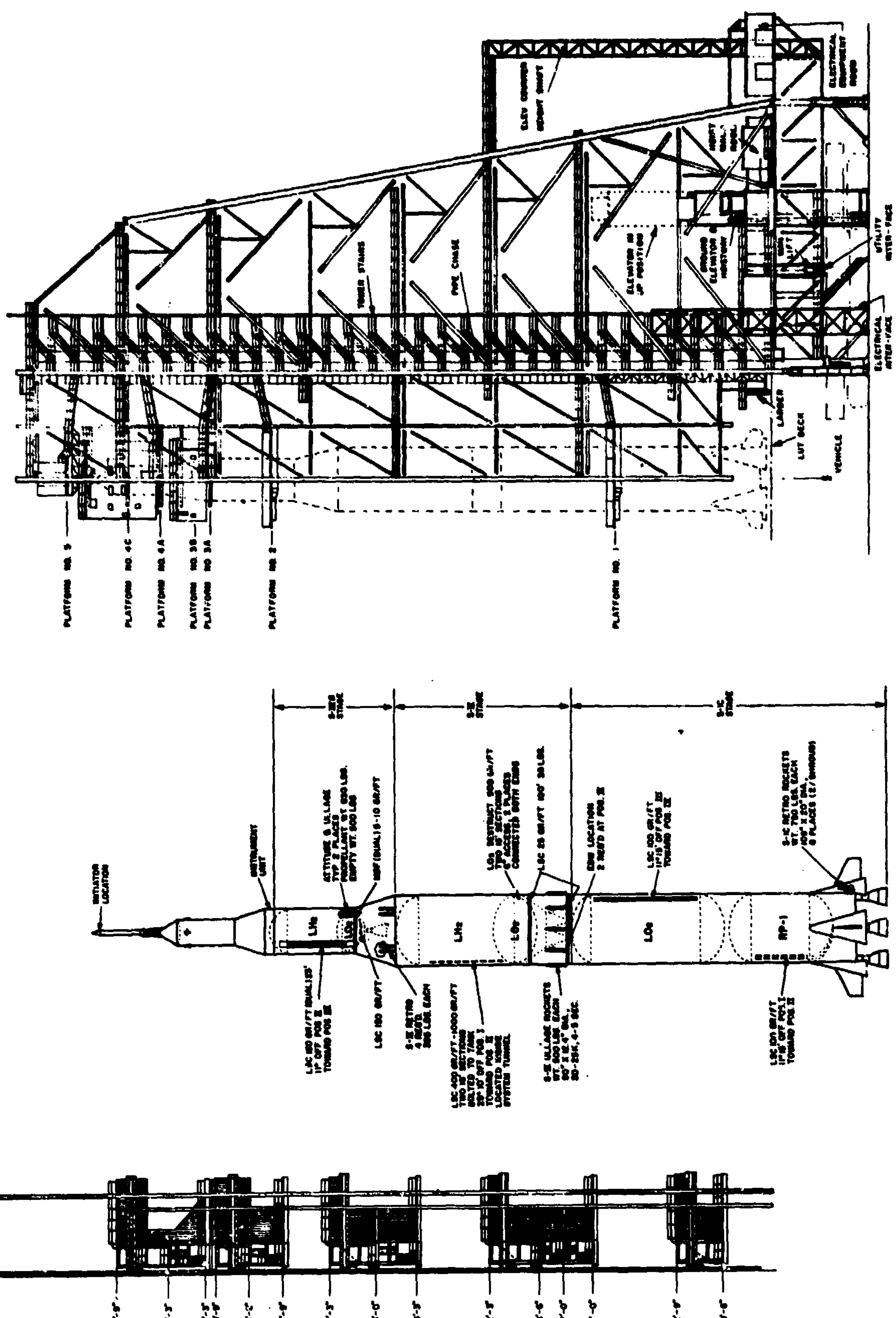

Fig. 10 Diagrams of Safety Circuits of Ordnance Items

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Fig. 11 Artist Concept of VAB Erection of SATURN

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vehicle in the VAB. Accordingly, a study was begun to evaluate these hazards, to form an hypothesis upon which to proceed. Briefly stated, these studies, which are not yet complete, have indicated that we can, by exercising careful operational control and by judicious handling of such devices (less initiating elements) install them in the VAB. The remainder of this discussion will be devoted to an outline of our revised checkout procedures and a rationalization of our control methods.

REVISED CHECKOUT PROCEDURES:

1. Stage buildup in VAB - 14 days in low bay, 54 days in high bay.

2. Ordnance will be installed on the 43rd thru 49th days of a 54 day work schedule in the high bay (for last 11 days, an extra hazard exists by virtue of the presence of the ordnance items.)

3. Transfer to pad for 30 day work schedule with initiating devices installed on 29th day (arming occurs 30 mins. prior to launch).

4. Advantages:

    a. Extensible work platforms provide controllable access to all sections when ordnance will be installed, thus simplifying installation procedures.

    b. Ordnance installation can be conducted on schedule regardless of adverse weather conditions.

5. Disadvantages:

    Will require special control measures and procedures.

DESCRIPTION OF ORDNANCE ITEMS: As you will note, the largest single item of concern is the launch escape rocket (LES) which weighs approximately 3170 lbs. Since the operating restrictions imposed by this item are more extreme than the others, we will discuss this first. Rationalizations applied to this will, in general, apply to the other items.

APPROACH: After a number of hours spent in self pity and tearful approbation, we decided to attack the problem as follows:

1. What are most likely mechanisms of initiation?

2. What is the magnitude of the expected reaction?

3. What are the major hazards - fire, blast overpressure, fragmentation, thermal (fireball) or others?

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Fig. 12

ORDNANCE ITEMS
SATURN V

PART I, SOLID ROCKET MOTORS

STAGE	ITEM	FUNCTION	COMPOSITION	APPROX. SIZE	PROP. WT.	BURNING TIME	THRUST
S-IC	Retromotors 8 each	To decelerate S-IC after separation from S-II *	Composite 72% NH_4 ClO_4	15.2" x 95"	270 lbs.	0.64 sec.	92,400 lbs.
S-II	Ullage Motors 8 each	To accelerate S-II & S-IVB **	Composite 82% NH_4 ClO_4	12.7" x 90"	300 lbs.	3.25 sec.	23,000 lbs.
	Retromotors 4 each	To decelerate S-II after separation from S-IVB *	Composite 72% NH_4 ClO_4	9" x 103"	264	1.5 sec.	34,000 lbs.
S-IVB	Ullage Motors 2 each	To accelerate S-IVB after separation from S-II **	Composite 78% NH_4 ClO_4	8.3" x 36"	59 lbs.	3.87 sec.	3460 lbs.
Apollo LES	Launch Escape Motor	Spacecraft escape means during abort	Polysulfide (Ammonium (Perchlorate Aluminum Powder	26" x 185.8"	2280 lbs.	3.5 sec.	155,000 lbs.
	Tower Jettison Motor	Jettison LES in normal launch		26" x 55.6"	147 lbs.	1.0 sec.	33,000 lbs.
	Pitch Control Motor	Direct Flight path of LES		8.8" x 29"	9.5 lbs.	0.5 sec.	6,000 lbs.

* Retromotors provide the thrust required to decelerate the S-IC Stage from the S-II Stage providing rapid and complete physical separation of these Stages during the S-IC/S-II and S-II/S-IVB separation respectively.

** Ullage motors provide vehicle acceleration to position the propellants in the S-II and S-IVB Stage to prevent the admission of vapor into the propellant feed system to insure successful ignition of the J-2 engines.

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ORDNANCE ITEMS

SATURN V

PART II INITIATORS, SEPARATION CHARGES, AND PROPELLANT DISPERSION SYSTEM (PDS)

STAGE	ITEM	QUANTITY	FUNCTION	APPROX. SIZE	EXPLOSIVES WT. UNIT	TOTAL EXPL. WT.	SENSITIVITY
	EBW Detonator	2	Propellant Dispersion System		1.4 gr.	2.8 gr	See Remarks (1)
	Safe & Arm	1			5 gr.	5 gr.	Self Contained After Installation See Remarks (2)
S-IC	CDF	8			2 gr./ft.		
	LSC	4		138' L	150 gr./ft.	2.9 lbs.	See Remarks (3)
	EBW Detonator	4	S-IC/S-II Separation		1.4 gr.	5.6 gr.	See Remarks (1)
	LSC	2		66' L	Piggyback 10/[illegible] gr./ft.	0.12 lbs.	See Remarks (2)
	EBW Detonator	2	Propellant Dispersion System		1.4 gr.		See Remarks (1)
	Safe & Arm				5 gr.		Self Contained After Installation See Remarks (2)
S-II	CDF	11			2 gr/ft.		
	LSC			132' L	600 gr./ft.	11.3 lbs.	See Remarks (4)
	EBW Detonator	2	S-II/S-IVB Separation		1.4 gr.		See Remarks (1)
	MDF	2		66' L	5 to 10 gr./ft.	0.07 lbs.	See Remarks (2)
	EBW Detonator	2	Propellant Dispersion System		1.4 gr.		See Remarks (1)
	Safe & Arm	1			5 gr.		Self Contained After Installation See Remarks (2)
S-IVB	CDF	6			2 gr./ft.		
	LSC	3		66' L	150 gr./ft.	1.4 lbs.	See Remarks (3)

REMARKS

(1) Exploding Bridge Wire Detonator will not fire and will remain operational during the following applications of power applied either pin to pin or pin to case:
a. 36 volts DC-0.1 ohm impedance source applied for 15 minutes
b. 115 or 250 volts - 60 cycle 0.2 ohm impedance source applied for 15 minutes.

c. 115 or 250 volts - 400 cycle 1.o ohm impedance source applied for 15 minutes.

d. 9000 volts from a 500 picofarad capacitor.

e. 500 volts from a one microfarad capacitor.

(2) Will not detonate except when shocked with a high explosive donar charge.

(3) Impact tests of up to 20,000 ft. lbs. will not produce high order detonation or propagation.

(4) Impact tests produced high order detonation of 400 gr./ft. lead covered LSS at energy levels of 2,000 ft. lbs. and above.

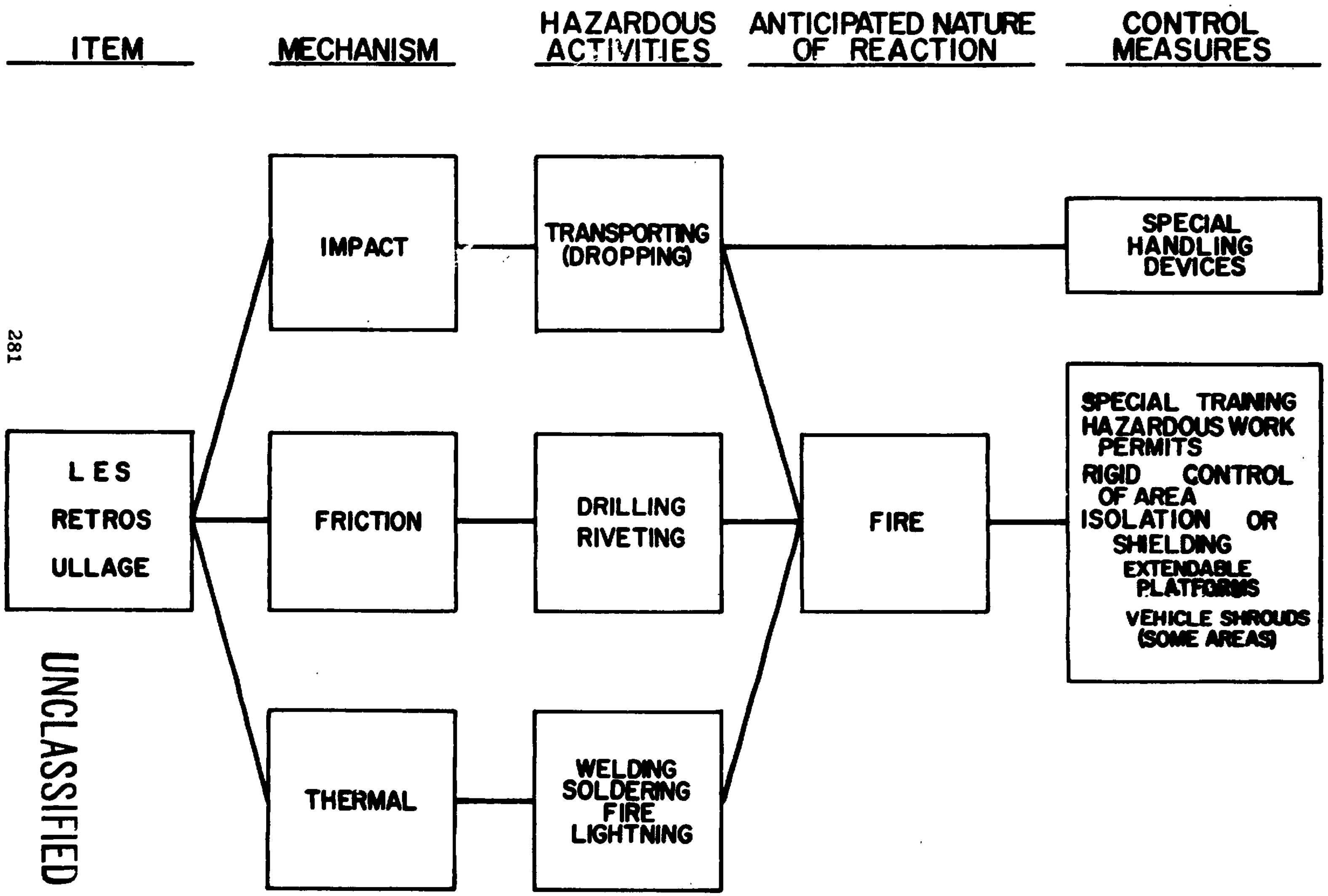
No test data available for 600 gr./ft. LSS.

Fig. 13

ROCKET MOTORS

MECHANISMS OF ACTIVATION

Fig. 14A



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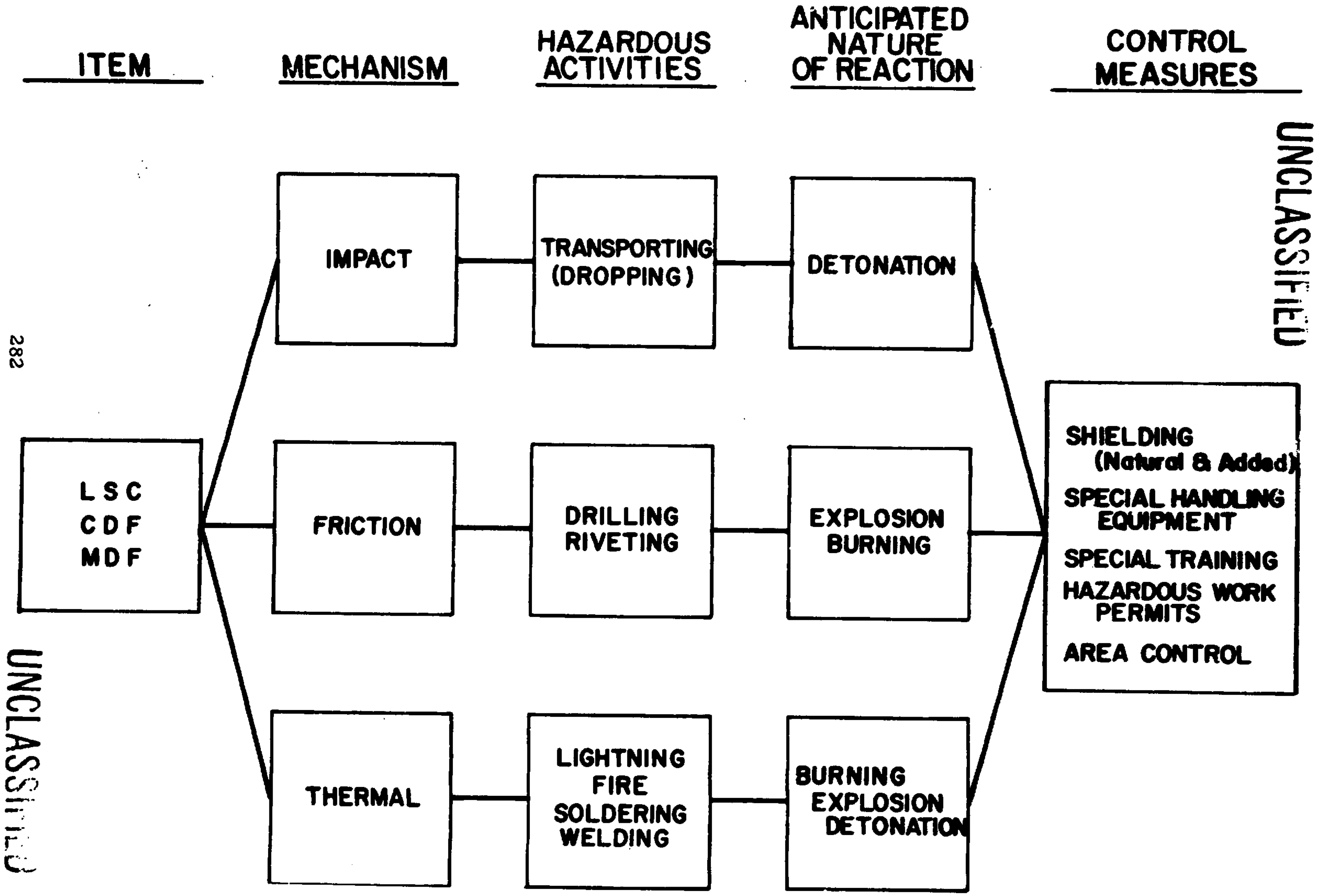
INITIATORS — DESTRUCT CIRCUITS

⁻.CHANISM of ACTIVATION

Fig. 14B



It was felt that the greatest hazard would arise in the period during which the item is transferred and positioned on the vehicle. Once the item is positioned, it is assumed that the mounting bolts would hold (design criteria) and the burning rates would approach normal.

Returning to the LBS motor as the largest single problem, here are a few of the specifications: size, weight, thrust, etc., compositions, hazard classification. (see figure 16)

If initiated in the normal manner, the following thermal and overpressure patterns would result in free air. As shown in the slide, temperature from combustion would reach 520°F at 258 ft. for 3.5 secs. and the overpressure contours would extend, as shown, to 170 ft. for 0.66 psi and 258 ft. for psi 0.0. (figure 17A)

The nozzle and most of the body of the launch escape motor are enclosed by platform A. Fortunately, the walls of the enclosures at each platform level provide us with a fair degree of protection, since they resemble some of the "frangible structure" types of construction we are currently evaluating (light weight aluminum and insulating material). The roof and flooring of the platforms are constructed of cellular sheet steel with a yield point of 33,000 psi, and a wear surface of aluminum.

In predicting the mode of failure, we feel that the walls will not become major fragments, and that the floors of the platforms will maintain their integrity below the level of the second extensible work platform. Platform A, as shown, would be expected to receive major damage. Platform B would be our buffer zone and Platform C would be a safe area. As with all the hypotheses to date, special studies will be conducted to verify these assumptions.

Thus, we feel that should the worst happen, we will be concerned primarily with areas shown. These are the areas which will be evacuated during transfer, positioning, use of heat or flame producing devices, etc. This will involve evacuation of an estimated 280 to 330 people for periods of 30 minutes to 6 hours.

As discussed previously, the design criteria for mounting brackets are such that all the ordnance items, if initiated (burning) will remain secure on their mounts. Thus, we can disregard the possibility of a ricocheting round after mounting.

With the LBS rocket in position, the next most likely source of ignition is application of mechanical force (by accidental drilling, riveting, etc., striking, or by heat - involvement in a fire). Activation by lightning has not been considered a credible mechanism of initiation in this facility, as a result of previous studies.

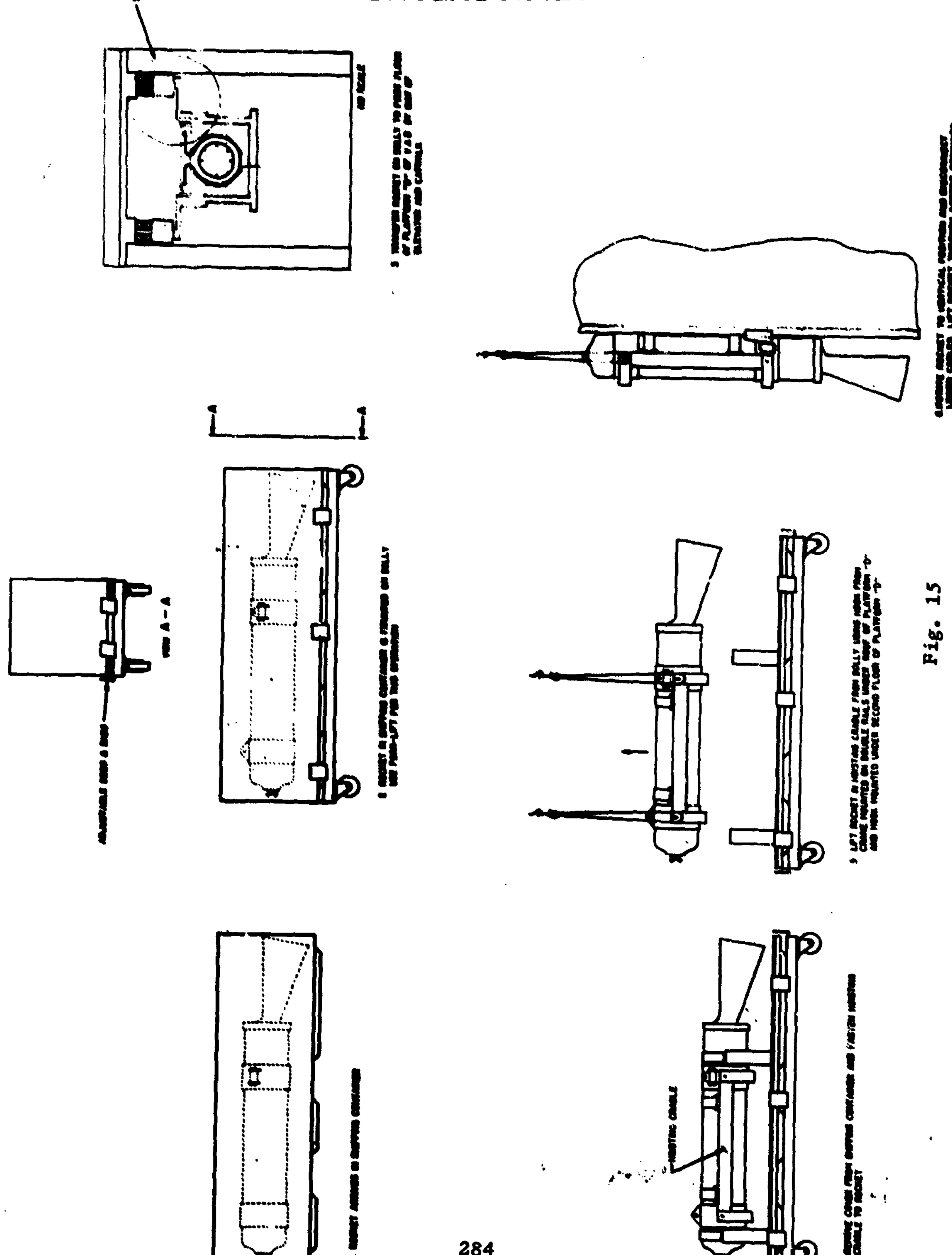
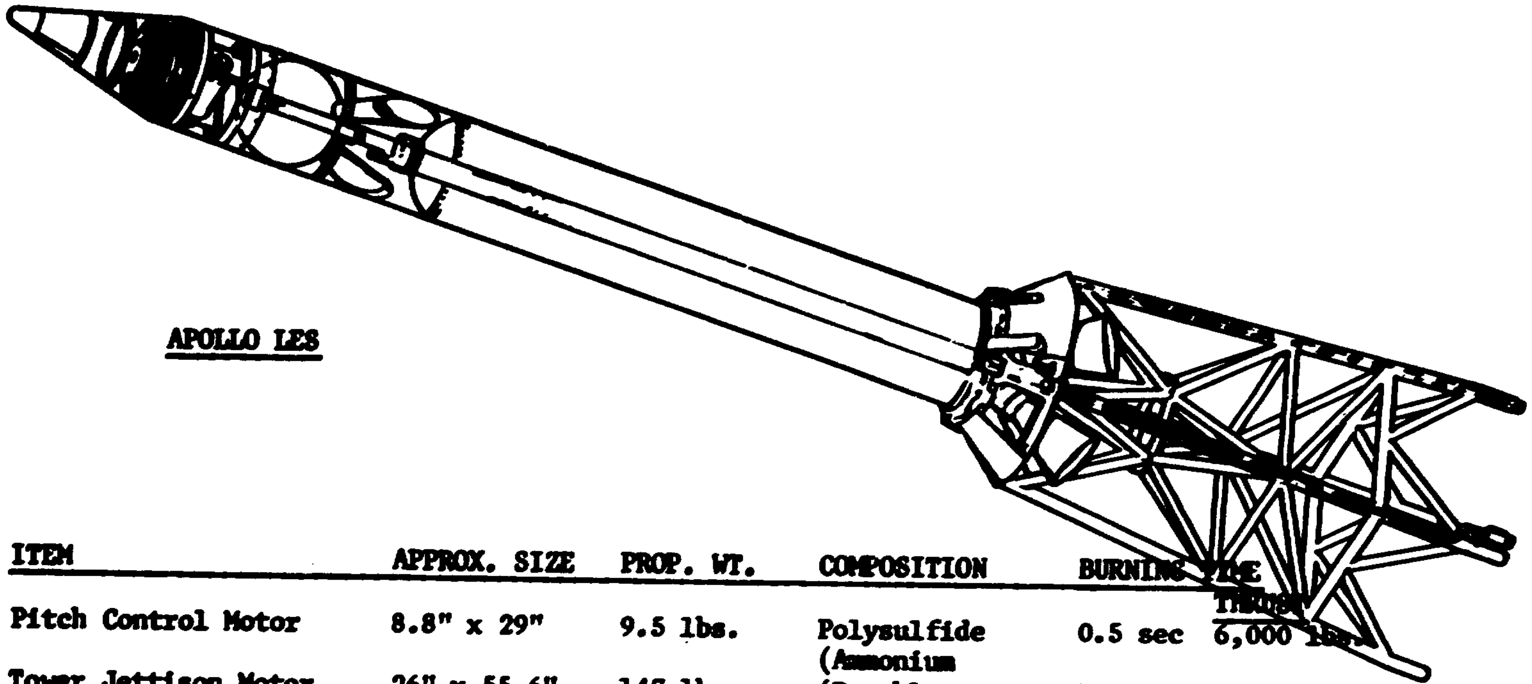


Fig. 15

LAUNCH ESCAPE TOWER

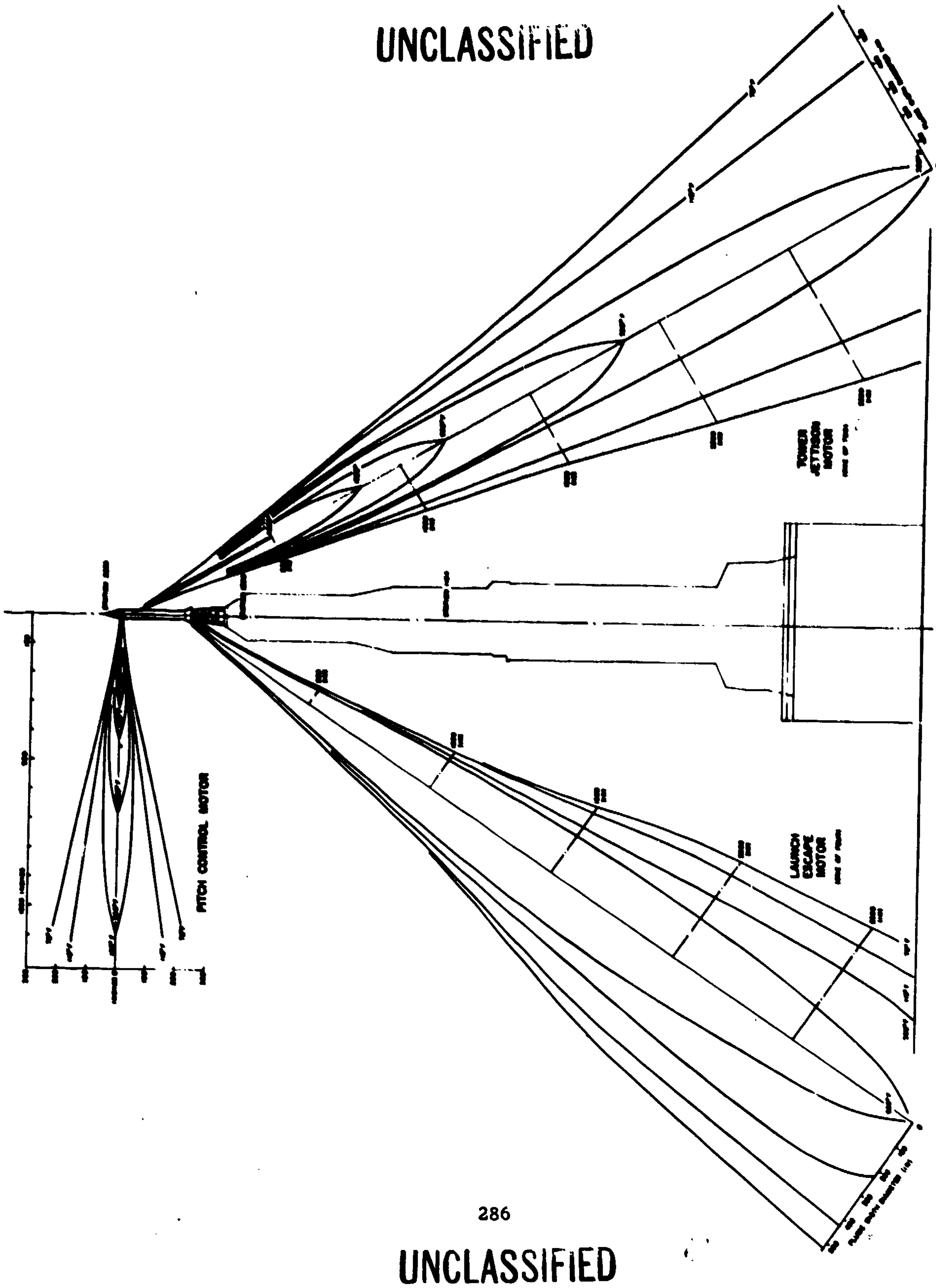


APOLLO LES

ITEM	APPROX. SIZE	PROP. WT.	COMPOSITION	BURNING TIME	THRUST
Pitch Control Motor	8.8" x 29"	9.5 lbs.	Polysulfide (Ammonium (Perchlorate Aluminum Powder	0.5 sec	6,000 lbs.
Tower Jettison Motor	26" x 55.6"	147 lbs.	"	1.0 sec	33,000 lbs.
Launch Escape Motor	26" x 185.8"	2280 lbs.	"	3.5 sec.	135,000 lbs.

Fig. 16

ST-100



LAUNCH ESCAPE SYSTEM PLUME GEOMETRY
Fig. 17

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SEA LEVEL
TOTAL RECOVERY PRESSURE
LES MOTOR

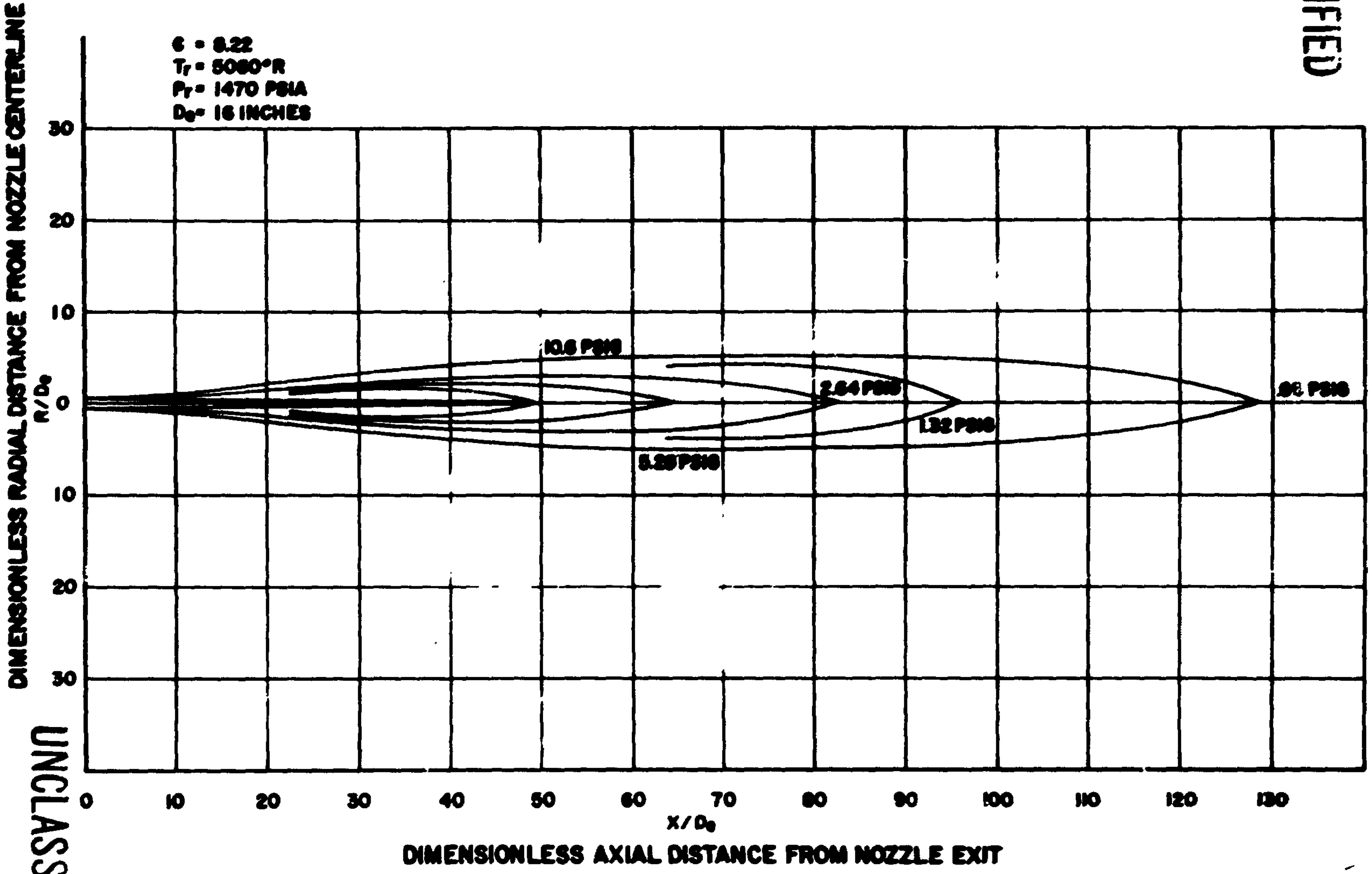

Fig. 17A

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The same general approach is being used to evaluate the hazards for retro and ullage rockets. Again, these will be more thoroughly investigated by our special study contract.

Ordnance destruct and separation charges offer the hazard of fragmentation over an appreciable radius if someone manages to, in some way, impart sufficient energy to the charge to detonate it. This, in effect, due to the nature of our destruct charges, creates a potential hazard over a considerable portion of the entire vehicle area, as shown by our slides.

The S-IC stage uses dual lengths - 22½ ft. long, 150 gr/ft LSC positioned vertically on the skin of the RP-1 tank and dual lengths 46½ ft. long, 150 gr/ft. LSC positioned vertically on the skin of the LOX tank 180° from the RP-1 PDS.

The S-II stage uses dual lengths of 600 gr/ft aluminum clad LSC, 38 ft. long, installed vertically in a systems tunnel along the skin of the LH_2 tank. Tests conducted by NAA using witness plates determined fragmentation to the rear of the cutting action to be very light.

For the LOX tank dual lengths of 16 ft. long of 2,000 gr/ft LOX teflon clad LCS are installed around the perispheres of the tank near the bottom at a point 180° from LH_2 (PDS) (Propellant Dispersal System).

The function of the LOX tank PDS is to open the tank and the shroud simultaneously.

The S-IVB stage uses dual runs of lead clad RDX in 4 sections, 20 ft. long, installed vertically on the skin of the LH_2 tank.

For the LOX tank dual runs of 150 gr/ft of lead clad LBS in three sections, a total of 12 ft, are installed along the perisphere of the tank near the bottom at a point 180° from the LH_2 tank PDS. Investigations of the fragment potential have indicated that these charges can produce lethal fragments at ranges up to 100 yds. However, the nature of these fragments is such that relatively light weight, portable shielding will defeat them.

Further, in checking the protection afforded by spoiler plates, natural shielding of the vehicle, etc., the problem becomes somewhat less acute. Indications, at present, are that local shielding, after installation will be practicable. However, evacuation of areas while charges are being secured will be in order.

These destruct charges are also constructed of materials of proven thermal stability and are quite difficult to detonate without initiators. As discussed previously, the CDF (2 g/f) will not detonate except when shocked with a primary explosive (EBW). The impact sensitivity of 25 grains per foot lead covered LSC is approximately 1,000 foot-pounds and

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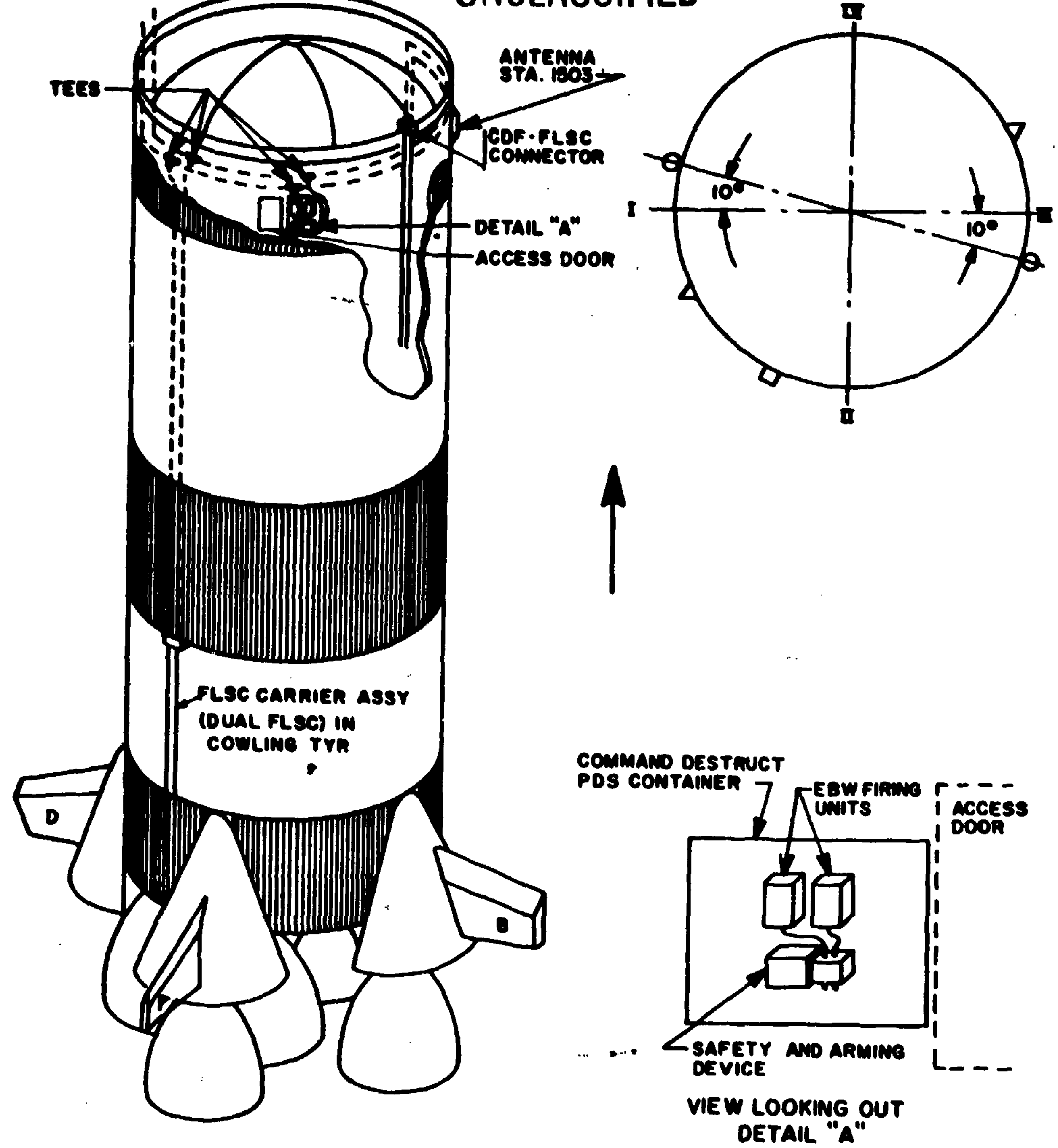

- - -	CDF ASSEMBLIES	AS SHOWN
———	LSC ASSEMBLIES	AS SHOWN THROUGH COWLING
O	RANGE SAFETY ANTENNAS	AS SHOWN
△	COWLING	20° FROM POS I → II & III → IV
□	ACCESS DOOR CENTER LINE	73° 20' FROM POS I → II

S-IC STAGE PDS

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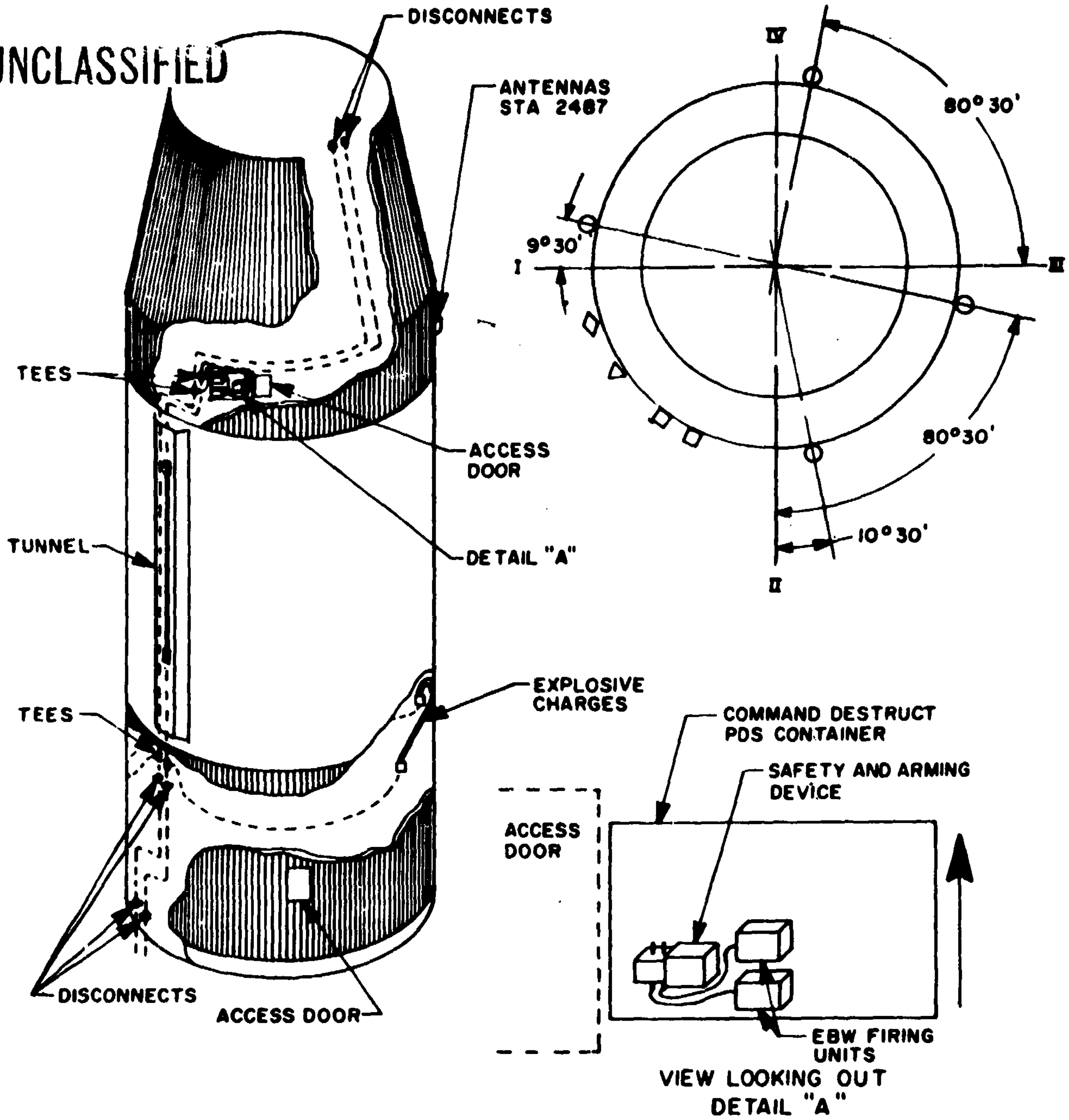
FIG 19A



- - - -	CDF ASSEMBLIES	AS SHOWN
———	LSC ASSEMBLIES	AS SHOWN THROUGH TUNNEL
○	RANGE SAFETY ANTENNAS	AS SHOWN
△	TUNNEL CENTER LINE	29° 10' FROM POS I → II
□	FWD ACCESS DOOR CENTER LINE	65° 30' FROM POS I → II
□	AFT ACCESS DOOR CENTER LINE	73° FROM POS I → II
◇	CDF LOCATION ENTERING S-IC	19° FROM POS I → II

S-II STAGE PDS

Fig. 19B

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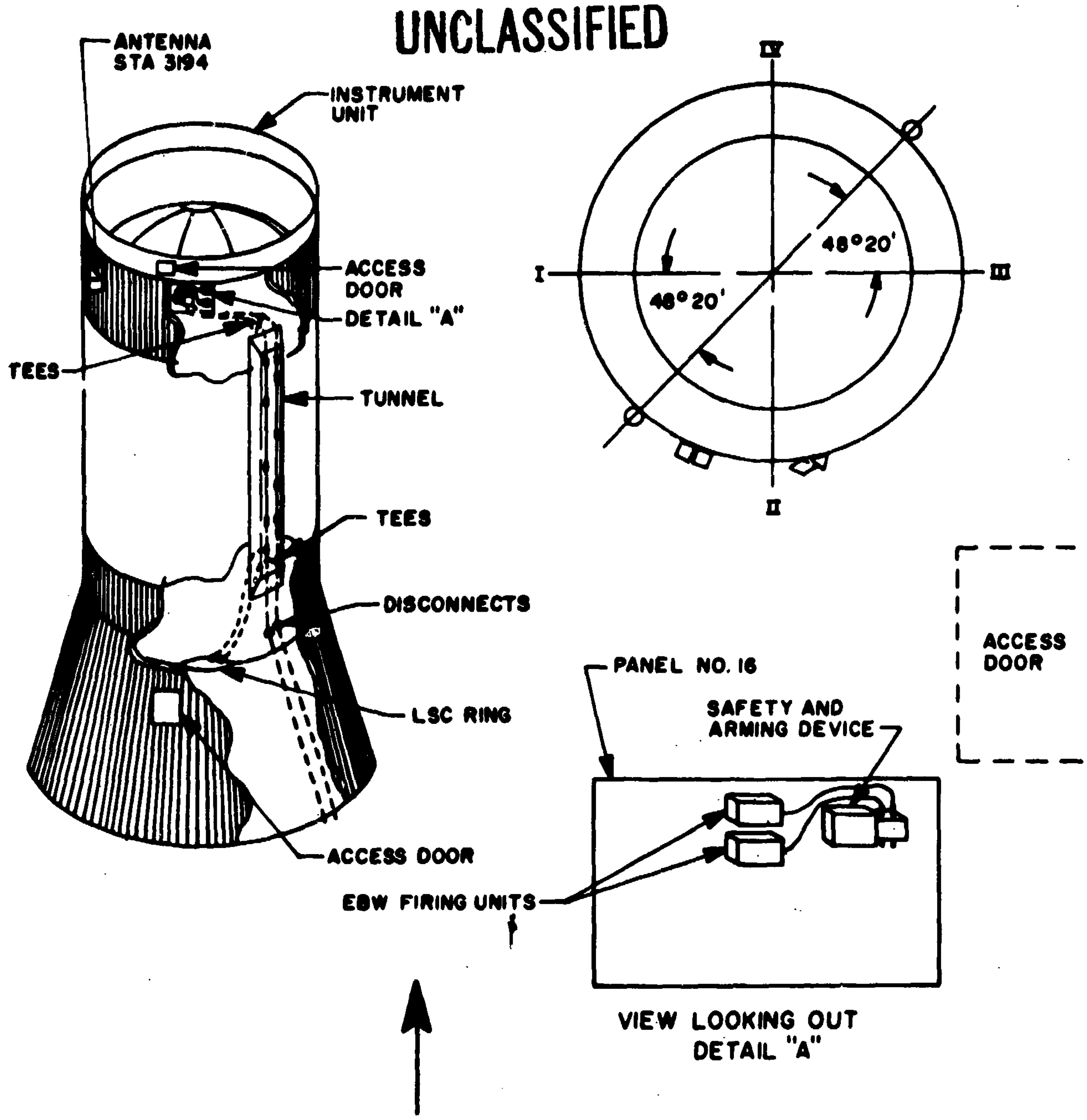

- - - -	CDF ASSEMBLIES	AS SHOWN
———	LSC ASSEMBLIES	AS SHOWN THROUGH TUNNEL
○	RANGE SAFETY ANTENNAS	AS SHOWN
△	TUNNEL CENTER LINE	10° FROM POS II → III
□	I.U. ACCESS DOOR CENTER LINE	74° 25' FROM POS I → II
□	AFT ACCESS DOOR CENTER LINE	73° FROM POS I → II
◇	CDF LOCATION ENTERING S-II	9° 15' FROM POS II → III

S-IV B STAGE PDS

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FIG 19C

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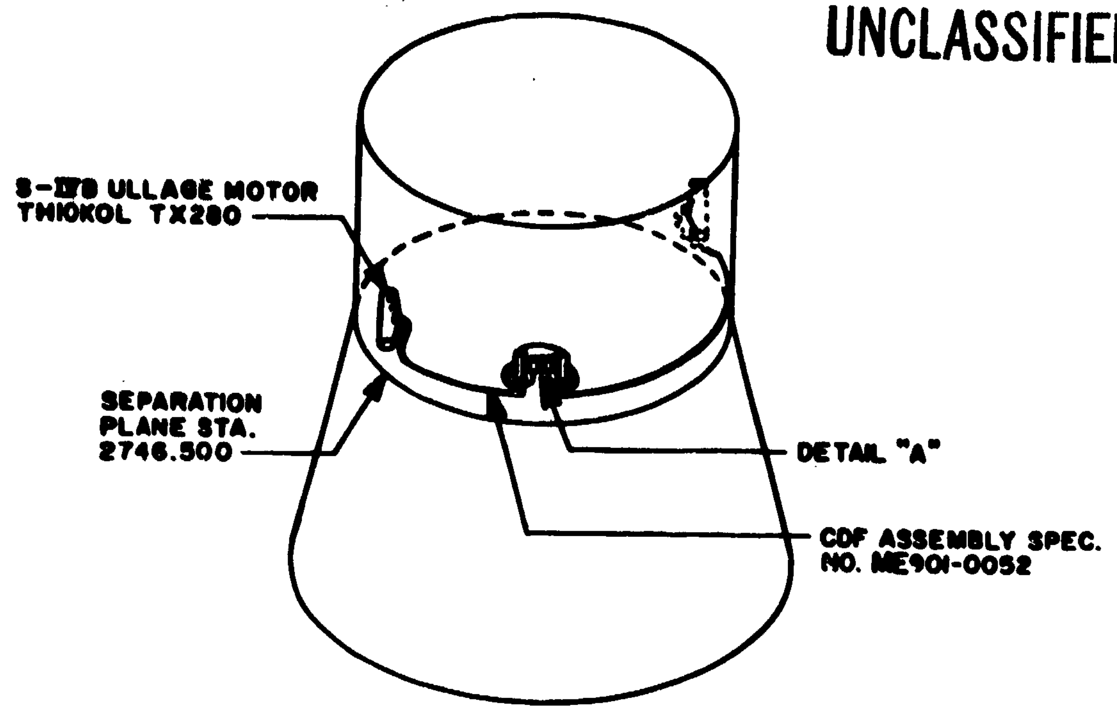

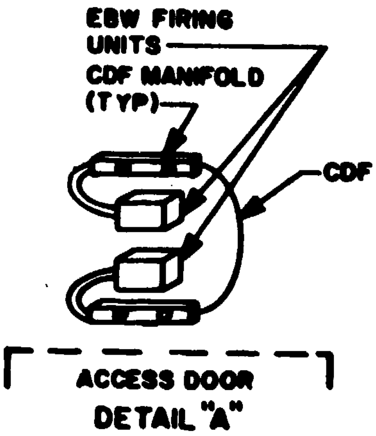

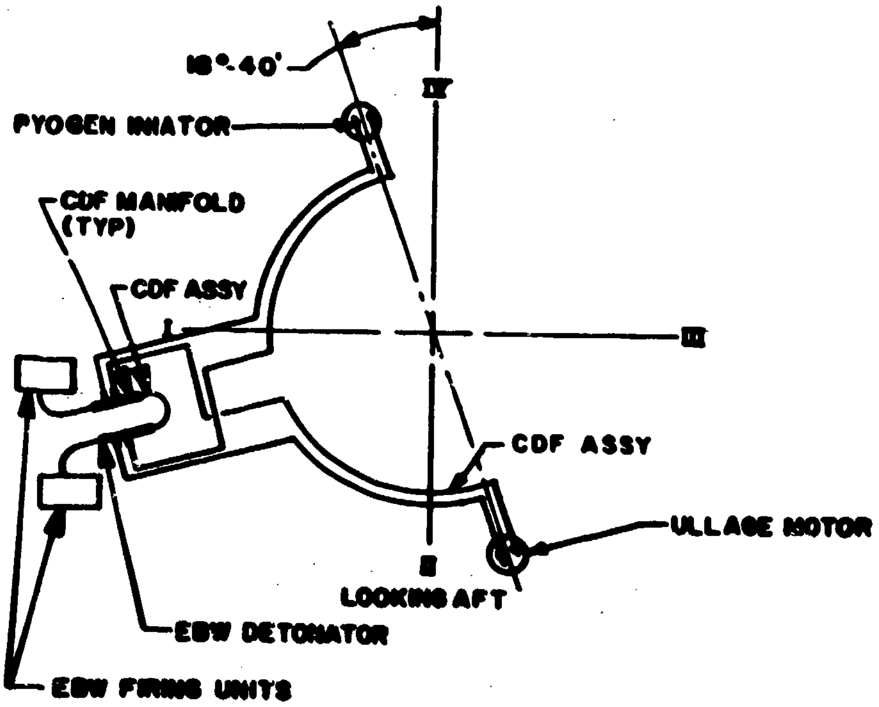

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Fig. 21A

S-IVB ULLAGE MOTOR IGNITION SYS.

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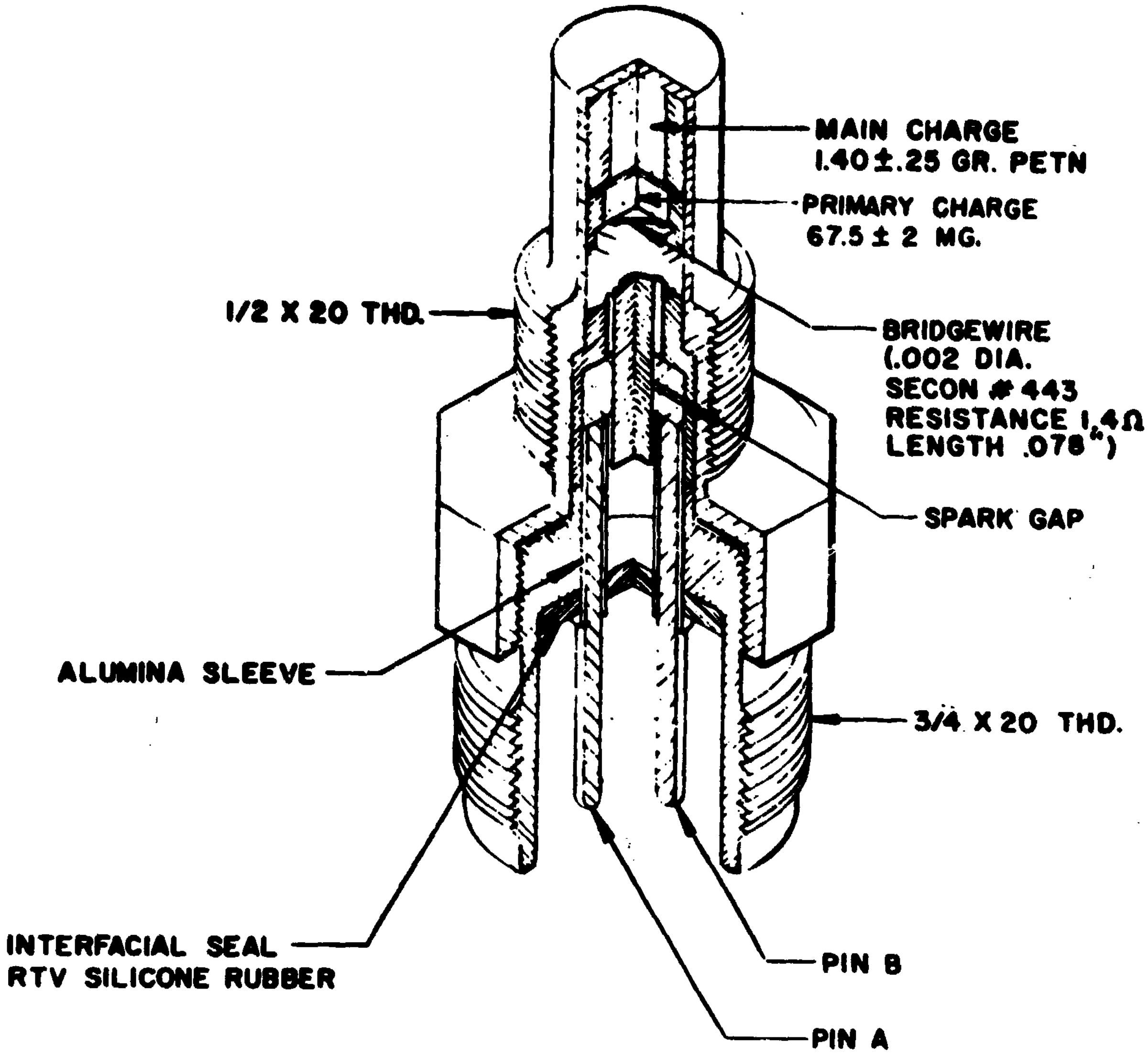

EBW DETONATOR
SPEC. NO. 7865742 N

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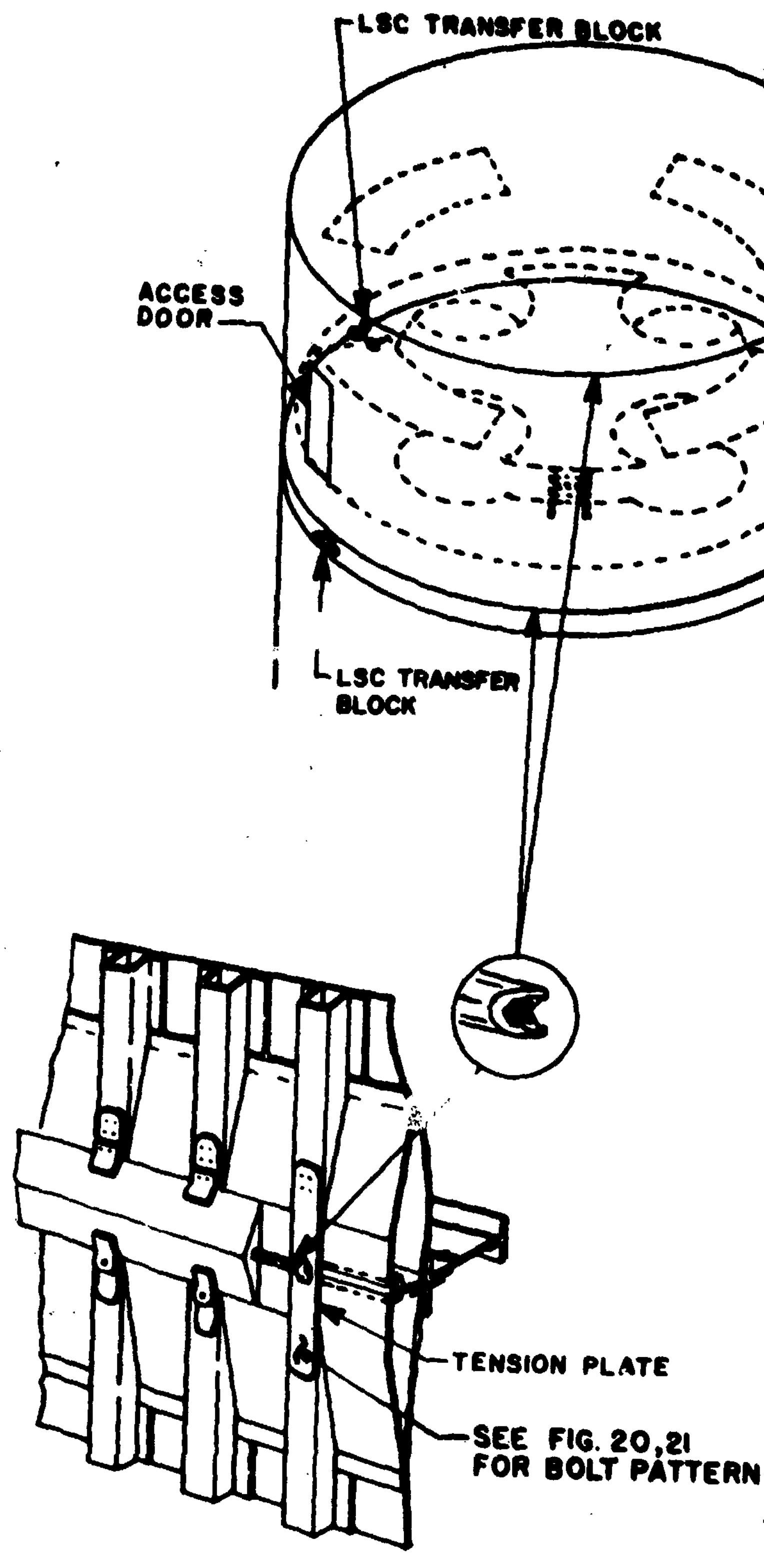
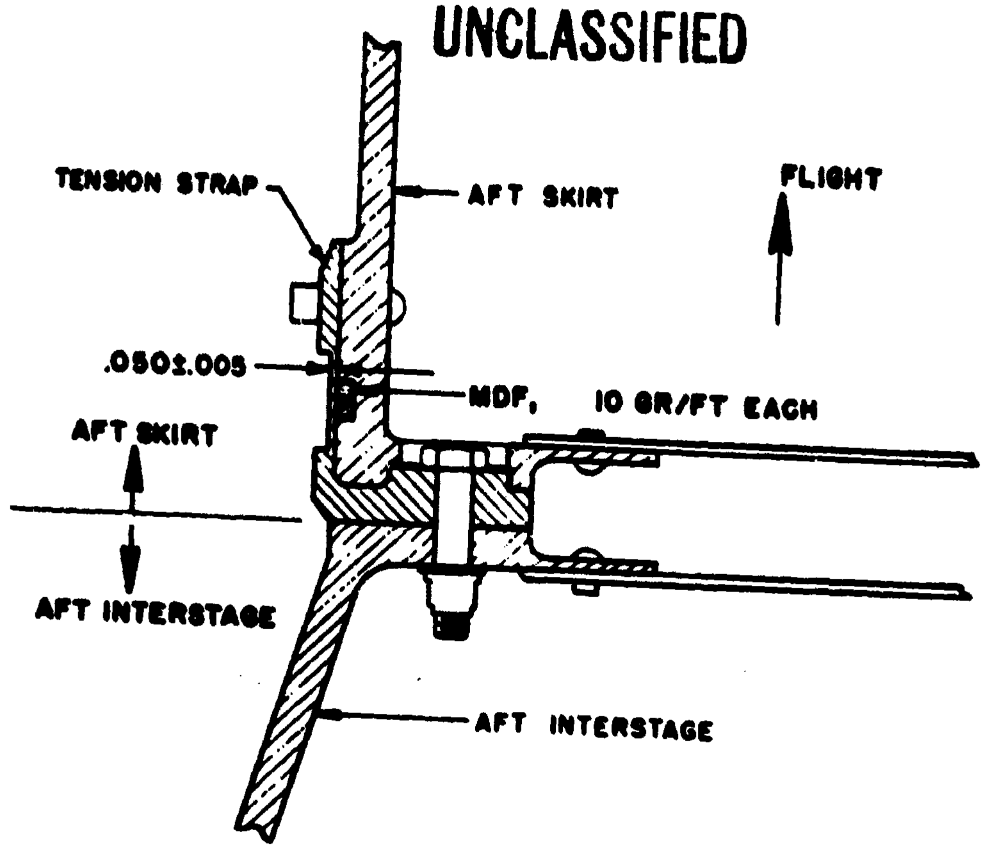
FIG 21B

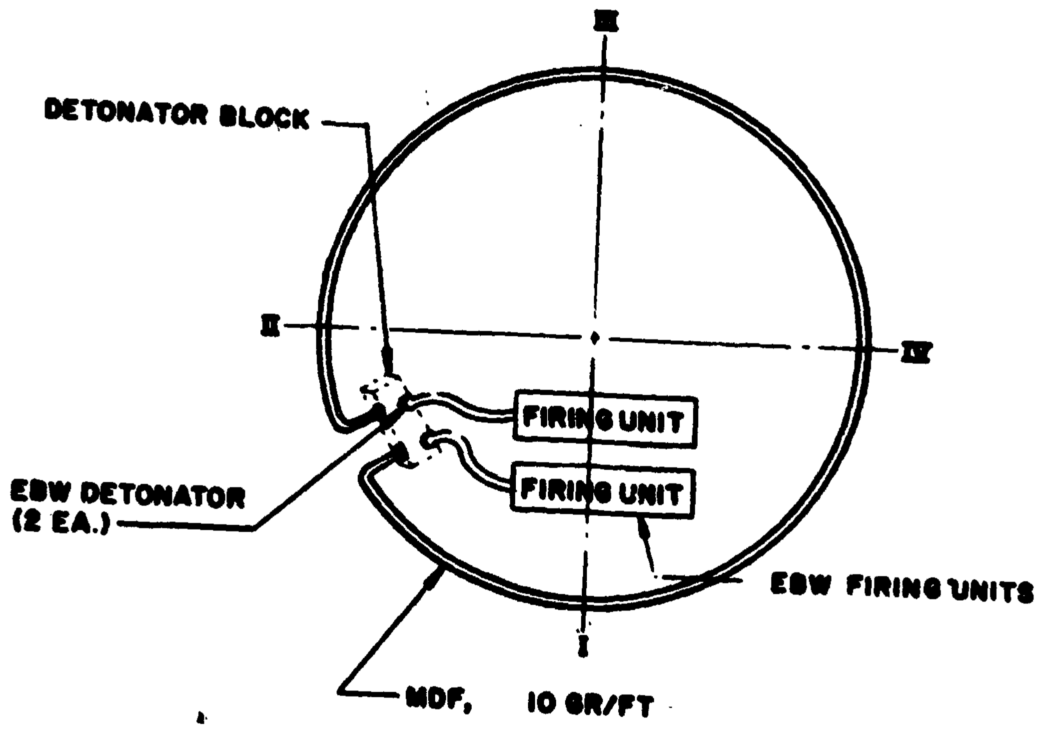


S-II STAGE
FIRST AND SECOND PLANE SEPARATION SYSTEM

FIG 21C

UNCLASSIFIED





S-IVB SEPARATION SYSTEM

FIG 21D

MDF (10 to 15 gr/ft) is considered of similar or less sensitivity. High order detonation of the LSC does not occur at impact energy levels up to 20,000 ft/pounds (500 wt. dropped 40 ft.) by test. The 25 gr/ft LSC when initiated in this manner produces a low order detonation in the area immediately beneath the striking surface and will not propagate.

OPERATING CONTROLS: Since the best way to prevent an accident is to provide for the best possible control of our personnel and to assure the highest practicable level of competence, we are leaning rather heavily upon three principal types of controls; namely, selective evacuation of personnel for periods of high hazards; specialized safety training programs; and careful control of operations which could conceivably result in providing a mechanism for initiation.

Evacuation procedures have been touched on lightly previously and in our discussion of the LBS and other ordnance items will be treated in a similar fashion.

Control of hazardous operations will be provided by 100% monitoring of same, by provision of permits to use sources of heat, mechanical or electrical power, etc. However, we are placing most of our money on safety training. As outlined, all personnel performing hazardous operations will be required to undergo a formal training program, followed by "on-the-job" training. Following this, they will receive a medical examination and will be certified by the Safety Division as having successfully completed their formal training, by their supervisor as having successfully completed their on-the-job training, and also as to their aptitude for the specific operation, and by the medical authorities as being medically fit.

Persons now employed in these types of operations will have their training reviewed, will be given the appropriate physical exam, and will be required to take a refresher training course.

Thus, we find that our carefree, clean living astronaut, who entered the program as a youth, now looks something like this, (Figure 24) by the time our assembly and checkout is complete.

SUMMARY:

In summation, assembly, checkout and launch of the second generation of SATURN launch vehicles is extremely complex, time consuming and, above all, demanding. The standards we must observe in order to assure safety of our personnel, the astronauts and the success of our mission are the highest yet conceived. The magnitude of a disaster is potentially so great that we cannot afford it, even assuming that the lives of personnel can be spared. In short, the success of our space efforts rests upon our ability to perform increasingly dangerous operations safely and efficiently.

SAFETY TRAINING COURSES

Type Course	Number Offered
Propellant Demonstration	2
Propellant Handling	3
High Pressure	2
Solid Propellant	1
Explosive Ordnance	2
Solvents & Miscellaneous Liquids	1
Toxic Propellant	1

Fig. 23

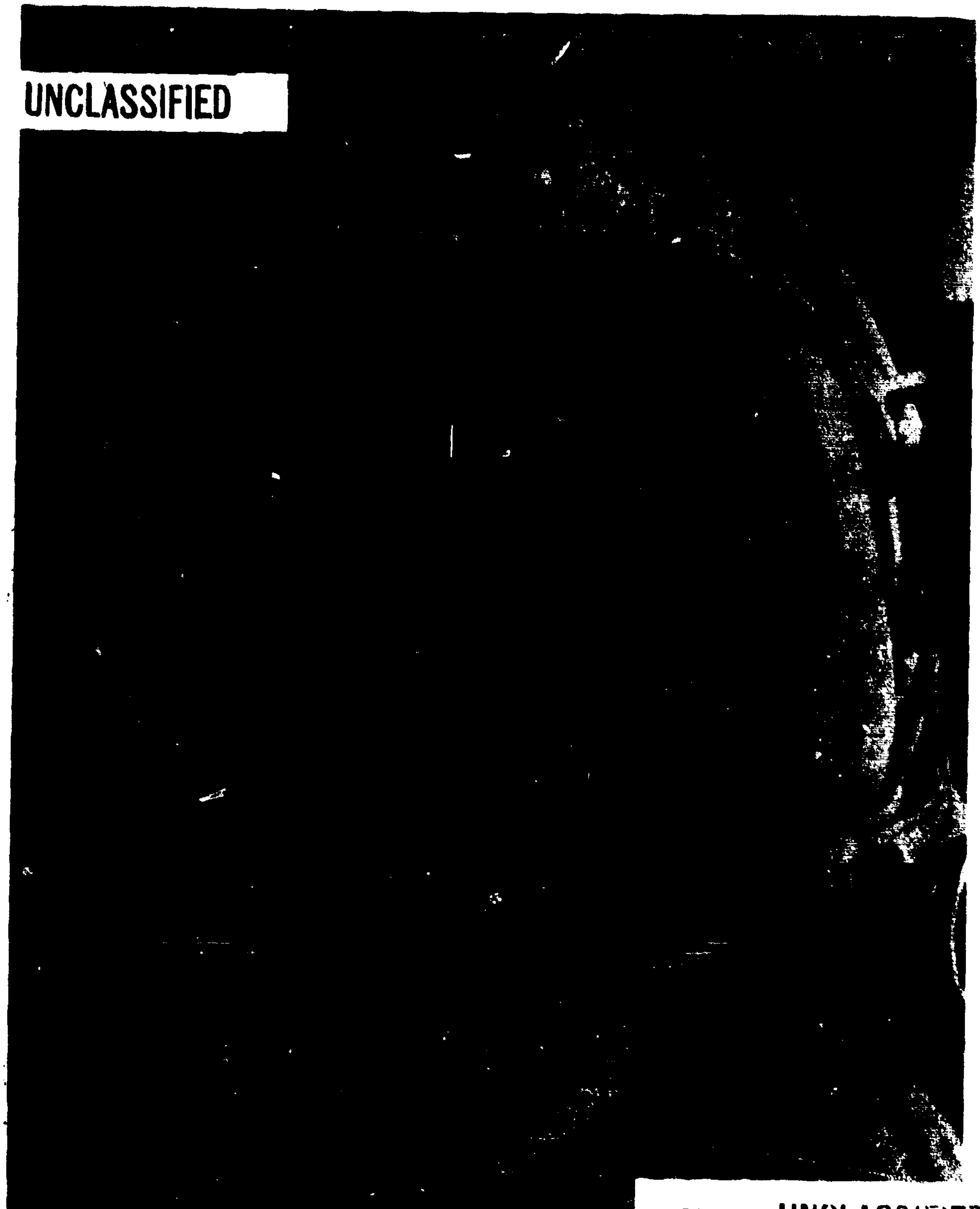


Fig. 24 UNCLASSIFIED

UNCLASSIFIED

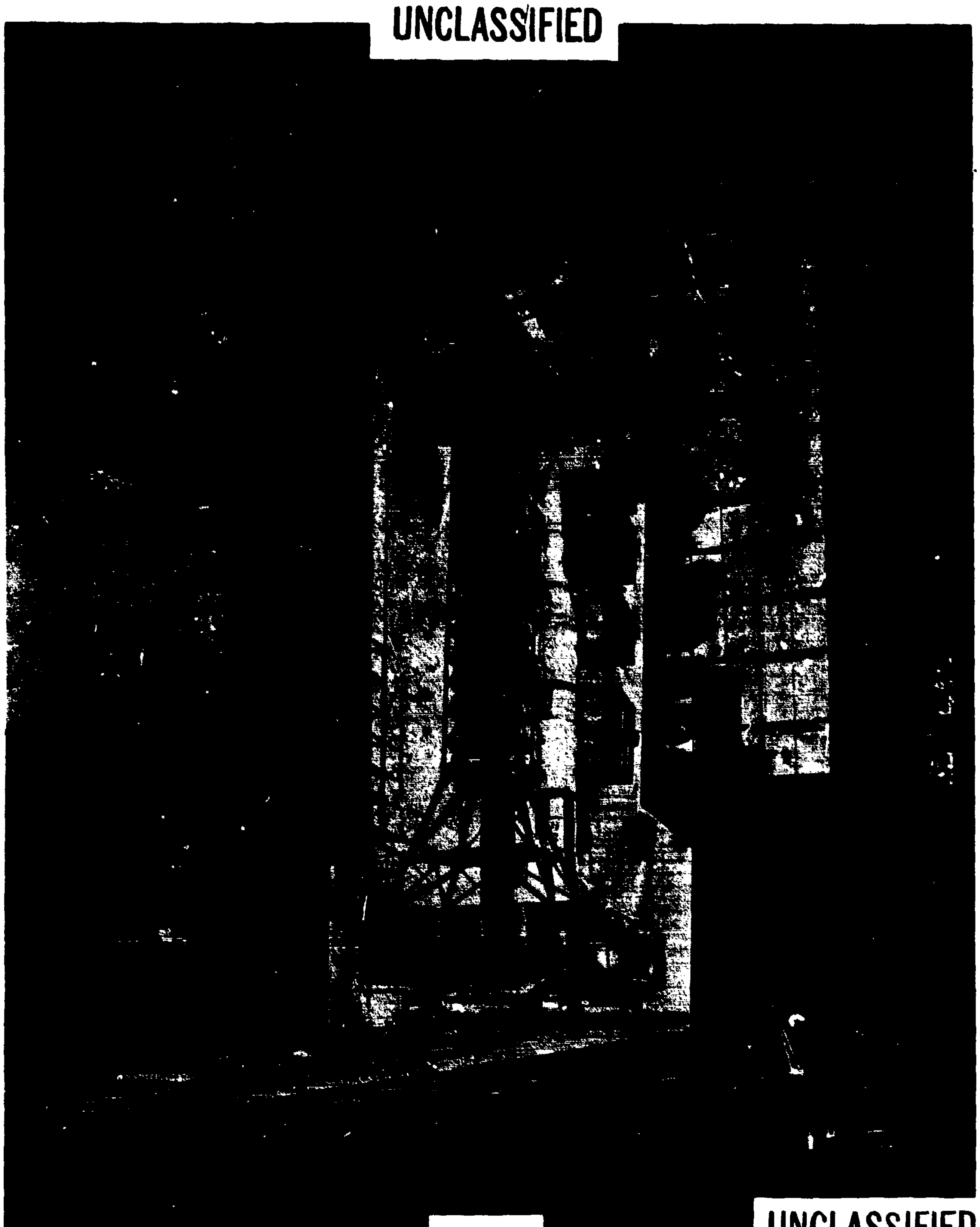


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Fig. 26

UNCLASSIFIED

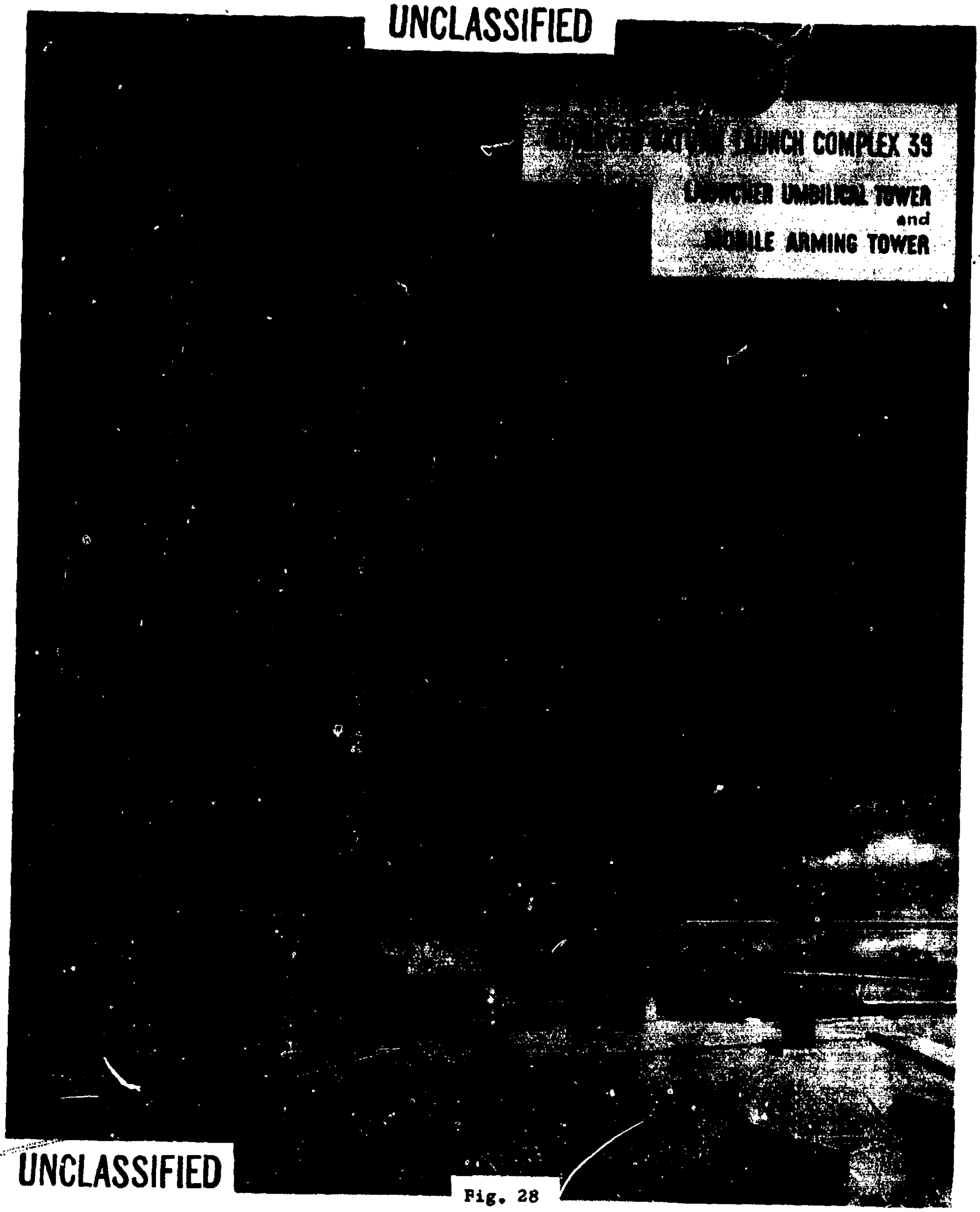

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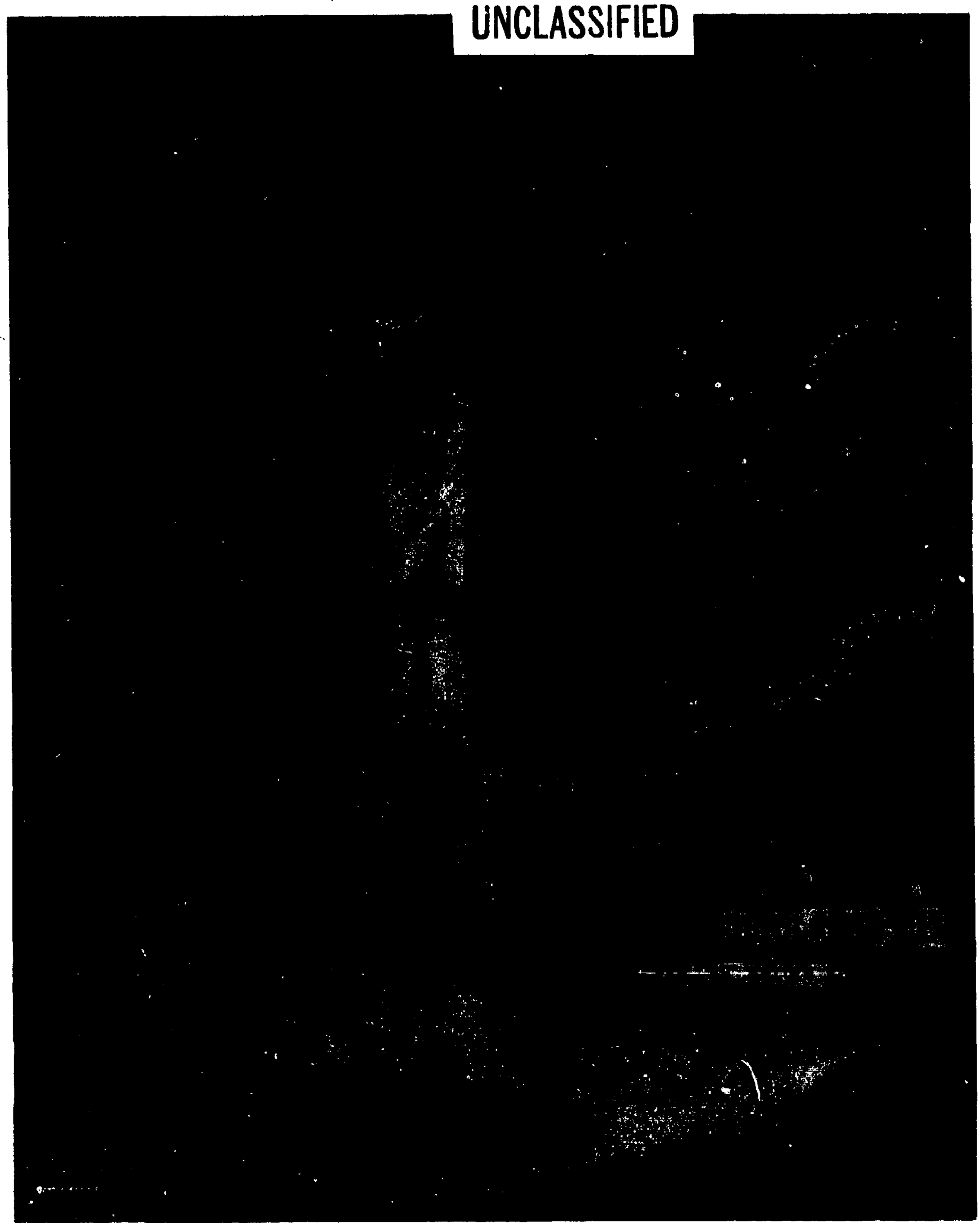
Fig. 28

UNCLASSIFIED



These demands, in turn, make it mandatory that we know everything possible about the hazards we face and that we assess them in a rational way.

The old, warm, lovable concepts of complete isolation of potentially hazardous operations has gone forever and our problem will get worse rather than better as time goes on. We intend to meet this challenge by:

1. Assessing the true nature of the risk.

2. Establishing reasonable safety standards and making them. public, i.e., no hidden safety factors.

3. Demanding the highest level of training and competence.

4. Assuring maximum participation in our safety efforts.

5. And, in the immortal words of Lefty Gomez, "by good, clean living and a fast outfield."

ENVIRONMENTAL POLLUTION ABATEMENT

Lt Col. Robert L. Peterson, USAF, BSC
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Headquarters, United States Air Force
Washington, D. C.

The Panel discussion addresses itself to Environmental Pollution Abatement and Missile Propellant Testing.

Some of you may ask why are we going to discuss pollution abatement with a group concerned with explosives safety? The charter for the Armed Services Explosives Safety Board includes rocket propellants in its definition of explosives. The developing and testing of propellants results in environmental pollutants.

Unfortunately, it seems that the most effective chemical candidates for use as rocket propellants are generally materials that are quite toxic and qualify for the doubtful distinction of causing the most difficult pollution abatement problems.

Disregarding the role of propellants as pollutants for a moment, I would like to discuss pollution in general. Pollution is a national problem. We cannot kick it under a rug or rationalize it away. That it is an urgent problem is apparent to anyone who looks at our lakes and streams, who lives in a city facing water shortage or possible outage because of lack of adequate unpolluted sources of supply, or to those of us who live in cities experiencing an all-too-frequent shroud of smog.

The pollution problem arose from the waste produced by a rapidly increasing population and an expanding dynamic industrial technology, coupled with a fixed amount of water available to dilute untreated or partially treated waste and, when the weather is not cooperating, a fixed volume of air into which untreated tons of waste are discharged daily.

Congress has recognized the pollution problem and has enacted legislation that assigns responsibility and certain programs for its control.

Pollution abatement is not a simple straightforward problem with an easy solution. I should like to enumerate some of the elements that make up this Gordian knot:

1. We are seldom faced with a simple or single class of pollutant. Contemplate for a moment the possible pyrolysis products from some of our propellants.

2. The pollutants (and again we can use propellants as the example) usually affect one or more components of our environment (air, water, soil, vegetation, man, animals), usually in different ways (not always detrimental), and in varying concentrations.

3. The problem of quantitation and qualitation is usually technically difficult and expensive.

4. Accurate criteria, around which precise engineering control procedures and equipment can be designed, are not usually available. There is also frequent conflict of opinion regarding acceptable standards by qualified professionals, to say nothing of the other variables encountered by those attempting to establish regulations.

You might say our dilemma is this: How can we test and develop the weapons systems needed to maintain our deterrent lead, when the very testing and development create pollution problems that violate the pollution abatement laws? Elements that are and need to be considered if we are to persevere are as follows:

1. The possible problem of pollution must be recognized when candidate propellants are being considered.

2. The cost of pollution surveillance and control, versus the technological advantages of a propellant, must be considered by management in selecting operational propellants.

3. Propellant test sites should be selected only after careful consideration of the pollution problem potential. Such consideration must include relative toxicity of the propellant and its pyrolysis products and possible population densities that would be exposed to toxicologically significant concentrations of pollutants.

4. Where atmospheric pollution is a potential problem, accurate meteorological information at the test site is essential for use in site selection and in pollution distribution and diffusion prediction.

5. Sampling networks should be established by bioenvironmental engineers to quantitate pollution.

Individuals having rule-making authority must be convinced that we in the defense community are vitally concerned about pollution control. We are and have been taking positive measures to study these problems. We are ready to share that knowledge and experience with them whenever the need arises and would encourage such partnership in the interest of developing the framework for good regulations.

FEDERAL RESPONSIBILITY UNDER THE CLEAN AIR ACT

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U. S. Public Health Service
Department of Health, Education & Welfare
Washington, D. C.

I am pleased that Colonel Peterson invited me to appear with him on this panel concerned with Environmental Pollution Abatement and Missile Propellant Testing. I am aware that you represent a significant cross-section of the nation-wide military-industrial explosives safety team working diligently in a cooperative effort aimed at improving and extending the science of explosives safety. Not only is it timely, but highly appropriate, that the Public Health Service join in this cooperative effort and I am glad to present certain highlights of the Clean Air Act of 1963 for which we have some responsibilities delegated by the Secretary of Health, Education and Welfare.

Cooperation in the control of all sources of air pollution, including that generated by rockets and missiles, is the keynote of the Clean Air Act as well as the theme of the Federal air pollution control program which has been developing steadily since 1955. That was the year when the 84th Congress passed Public Law 159, the first Federal legislation in this country relating exclusively to air pollution. Provisions of that law enabled the Public Health Service to begin a program limited at first to research, training, dissemination of information, and technical assistance.

Under the authority of that first Act, a multi-disciplined research program grew to include a broad range of investigations of the nature, effects, behavior, and control of air pollution. Technical assistance capability was shaped around early recognition that effective control would depend upon (1) greatly increased knowledge of the types and amounts of pollutants being discharged to the atmosphere, (2) better understanding of the meteorological factors that influence dispersion of pollutants in the atmosphere, (3) more sophisticated knowledge of the physical and biological effects of pollutants in relatively low concentrations, (4) identification and appreciation of the relative importance of specific air pollution sources, such as motor vehicles, and (5) improved information on the administrative, legal, social, and economic factors involved in the control of air pollution.

Initial activities were divided between two parallel programs, one centered on medically-oriented research, and the other on physical sciences and engineering. In 1960, these two programs were combined

*Chief, Federal Agencies Section, Abatement Branch, Div of Air Pollution

into one administrative unit identified today as the Division of Air Pollution in the Bureau of State Services of the Public Health Service.

Changes in legislative authority were few between 1955 and 1963. In 1959 a provision was added to the law directing, in effect, Federal Agencies to observe good practice in controlling air pollution arising from Federal property and to cooperate to that end with State and local air pollution control agencies and with the Department of HEW. In 1960 an amendment to the law directed the Surgeon General to make a two-year study of the health effects of motor vehicle pollution and to report his findings to Congress. In 1963 the Clean Air Act completely replaced PL 159 and it contains some substantial changes.

One fundamental item of national policy which was not changed by the new law is that primary responsibility for control of air pollution rests with State and local governments, the chief objective of the Federal air pollution program being to provide leadership and assistance to State and local control programs throughout the country. The new Act, however, greatly improves the Federal Government's capabilities to aid State and local governments, to encourage them, and even to stimulate them to increased levels of activity. For example:

1. The preamble to the Clean Air Act states that Federal financial assistance is essential for development of cooperative Federal, State, regional, and local programs to prevent and control air pollution. Authority was therefore given, for the first time, for Federal grants to be awarded directly-to non-Federal control agencies on a matching basis to aid them in initiating, developing, or improving their programs.

2. The Clean Air Act provides, also for the first time on the Federal level, legal regulatory authority for the abatement of certain air pollution problems. This regulatory, or enforcement, authority is clearly intended to supplement the abatement powers of state and local governments and it can be exercised in two types of situations:

First, with respect to an interstate problem in which air pollution arising in one state is alleged to endanger the health and welfare of persons in another state, the Secretary of HEW may, on his own initiative or in response to request by officials specified in the Act, initiate formal proceedings for abatement of the pollution as may be found necessary.

Second, with respect to a purely intrastate air pollution problem, the Secretary may invoke abatement proceedings, but only in response to official request from designated officials within the State involved. The abatement procedures authorized in the Clean Air Act are similar to

those used for several years under provisions of the Water Pollution Control Act. They involve a course of action which can include consultation, conference with cognizant official agencies, public hearings, and finally suits in Federal Courts by the Attorney General of the United States.

Substantial change in the scope of the Federal program is reflected in other provisions of the Clean Air Act. For example: the Secretary of HEW is directed to develop, publish, and to recommend criteria for air quality for the guidance of State and local authorities in establishing local standards for source emissions and for ambient air. Present work in this area has been centered on oxides of sulfur, and photochemical oxidants such as ozone and peroxyacylnitrate, but a variety of other pollutants such as the oxides of nitrogen, carbon monoxide, aromatic hydrocarbons, lead, and various particulates will be tackled later.

Another new provision of the Clean Air Act relates specifically to pollution generated by motor vehicles - and much effort intended to strengthen this provision of the law is being exerted by members of the present Congress. It is now abundantly evident that the temper of the times reflected in Congress requires drastic reduction of air pollution caused by motor vehicles in densely populated areas.

Another important provision of the Clean Air Act, contained in Section 7, applies specifically to Departments and Agencies of the Federal Government itself. This provision supports the general premise, first formalized as an Executive Order in 1958, that Federal agencies should be exemplary in preventing and controlling air pollution arising from government property. When that policy was first incorporated into law (in 1959) it said in effect that Federal agencies should clean house if it was in the national interest to do so and if money could be found within available appropriations.

Section 7 (a) of the Clean Air Act still contains, the same language, but Section 7 (b) was added to give the Secretary of HEW discretionary authority to institute a system of classification of Federal sources for which permits would be required. Along with implied authority for establishing some Federal standards, Section 7 (b) requires an annual report to Congress on the status of such permits. This annual report was intended to be more than a report of progress. Its prime purpose was to bring to the attention of Congress Federal air pollution problems for which money was needed or, perhaps, had not been sought by the agencies.

The Secretary has held in reserve implementation of the permit system which when strictly enforced among the independent yet coordinate agencies of the Federal Government whose missions might be jeopardized by denial of a permit, raises serious questions from the point of view of determining relative importance and priorities of missions.

A procedure more direct and much less complex administratively was conceived and initiated by the Bureau of the Budget last year. This was an amendment to BoB Circular A-11 directing that all new Federal construction projects must contain estimates for the control of air and water pollution control in accordance with instructions of the Public Health Service. This means that all Federal departments and agencies must now anticipate their own air pollution potentials and seek funds with which to effect control.

We think this action, yet to be completed by the executive branch of the Federal Government, is highly significant as concrete evidence of the growing national concern with the quality of the air we breathe. Additional evidence in this regard was furnished by President Johnson recently when, commenting on problems accompanying daily disposal of half a billion pounds of solid wastes, he said,

> "A prime National goal must be an environment that is pleasing to the senses and healthy to live in.
>
> "The Federal Government is already doing much in this field. We have made significant progress. But more must be done."

Later, in the same vein of thought, the President said:

> "I am directing the heads of all Federal Agencies to improve measures to abate pollution caused by direct agency operation, contracts and cooperative agreements. Federal procurement practices must make sure that the Government equipment uses the most effective techniques for controlling pollution."

More significant evidence is reflected by very recent Congressional action in consideration of a number of pieces of new legislation which in essence puts all Federal agencies on notice that Congress expects us to recognize our potentials for contributing to the Nation's air pollution burden and to seek funds necessary to prevent it. We must, in other words, provide leadership by deed as well as by word.

Such expressions in the highest levels of our Government clearly indicate the long delayed emergence of a consensus that protection of this Nation's air supply against pollution, inevitably concomitant with our advanced technology and increasing population density, is not only essential but requires effective budgetary planning.

Now, having reached that point, I think it is reasonable for scientists and engineers, such as we gathered here, to subscribe to the point of view that air pollution problems generated by activities of the Federal Government cannot be neglected and require serious attention.

This is not to say that we have no tough engineering problems some unique to our various missions being carried on in the National interest. Certainly the safe disposal of millions of cubic feet of wood gleaned from New York Harbor by the Army Corps of Engineers will not be accomplished by the same methods applicable to safe disposal of a few thousand pounds of explosive beryllium-contaminated wastes in a region of low population density. And certainly no scrubber has yet been built to collect the huge quantities of smoke and off-gases from the test firing of a 260-inch solid propellant rocket motor. Nevertheless, procedures involving meteorological and other forms of pollution control are available and must be used to assure that public health and welfare in this Nation are protected even on operations of such large scale.

My purpose today, therefore, has been to acquaint you with the general, rather than specific, nature of our mutual responsibilities under the Federal Clean Air Act of 1963 and to indicate the present Federal policy toward air pollution control. If there ever was a policy requiring interagency cooperation and a team approach, this is it. In this team approach the Department of Health, Education and Welfare often finds itself in the triple role of coach, referee, and scorekeeper.

The Clean Air Act provides a fresh and powerful stimulus for all of us in promoting cooperative efforts to assure that our environment is maintained in a manner which, as the President said, "shall be pleasing to the senses and healthy to live in."

INDUSTRIAL HYGIENE ASPECTS OF TESTING BERYLLIUM ENRICHED PROPELLANTS IN ROCKET MOTORS

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Air Force Rocket Propulsion Laboratory
Edwards, California

INTRODUCTION: The testing of rocket motors with propellants containing beryllium as an ingredient was initiated at the Air Force Rocket Propulsion Laboratory (AFRPL) in March 1963. Due to the toxicity of beryllium, a very extensive industrial hygiene and safety program was adopted. The health and safety program had a two-fold objective: (1) To protect personnel, both employees and neighbors of AFRPL, and (2) To assess the toxic hazard associated with this new use of beryllium.

To accomplish these objectives, a deliberate step-by-step scale-up of the motor size and testing frequency was adopted. An extensive environmental monitoring plan parallelled this scale-up program. Large safety factors were deliberately incorporated into the scale-up program which were only relaxed after field sampling data justified such a relaxation or assured us the next step could be safely accomplished.

Since the initial firings in 1963, over 30,000 environmental samples have been collected and analyzed. A field diffusion study to develop equations for predicting the concentrations of beryllium in the exhaust cloud has been conducted. A climatological study of the AFRPL complex was conducted for one year and plans for a fixed meteorological network patterned after the WIND systems/1 at Cape Kennedy and Vandenberg have been finalized.

The purpose of this report is to describe the industrial hygiene program at AFRPL for testing beryllium containing propellants and present the results of the environmental monitoring program. This will include the in-plant and neighborhood sampling program, results of a motor failure, and a brief summary of the diffusion program.

STATIC TEST FACILITY

The beryllium static test facility is located in a remote area at AFRPL. This area was selected primarily due to its isolation and location with respect to the prevailing winds and populated areas.

A two-position test stand separated by an earth-filled steel revetment comprises the present test stand. The two test stands are rated at 10,000 and 75,000 pounds of thrust. The stands are mounted on concrete

pads which extend to about 30 feet aft of the nozzle. Wash water drains to a sump tank below the pad and thence to an open-ended steel holding tank approximately 200 feet from the stand. Water from this tank leaches to the soil.

The test stand is the apex to a network of air samplers used in field diffusion experiments. Twelve 102° arcs extending to 9600 meters (six miles) have been bladed for four-wheel drive access. A system capability of over 550 remotely controlled air samplers is available on this grid.

Two other test stands are also located in the immediate area, all using the same blockhouse. A 204 foot meteorological tower with four levels of wind and three levels of temperature measurements is located 200 feet upwind of the beryllium test stand. A drive-on vehicle wash rack is located at the exit from the diffusion grid. Two "change-house" trailers with a shower separating the work clothes and street clothes locker rooms are located in the complex. Two shop buildings comprise the remainder of the test complex.

EXHAUST CLOUD DIFFUSION STUDIES

Atmospheric diffusion studies, aimed primarily at the development of quantitative statements of dilution rates of rocket motor exhaust cloud pollutants have been conducted at AFRPL. There are significant differences between these studies and other diffusion studies conducted to solve related Air Force problems. /1, 2, 3, 4

The basic difference is the character of the pollutant cloud. The cloud generated by the short burst of a rocket motor can be described as a puff, or quasi-instantaueous volume source, while those previously studied were characteristic of a plume or continuously emitting source. It is generally understood that diffusion ofpuffs differs from that of plumes, however, the laws which govern the diffusion of puffs are not well known. The few investigations of the behavior of puffs have invariably had quite limited objectives so that data appropriate to the study of diffusion of rocket motor exhausts were practically existent.

A preliminary analysis of the problem at AFRPL in 1962 indicated that a substantial field test program was necessary to generate the data required for the solution of the immediate operational problem, namely, static testing rocket motors. At the request of AFRPL, the

Air Force Cambridge Research Laboratories undertook the design and direction of the field test program and the subsequent analysis of the resulting data. This program, called Project Sand Storm, was conducted from March - November 1963.

Project Sand Storm

There were 43 diffusion experiments conducted during this project. All experiments were conducted under thermally unstable conditions, with winds generally greater than five knots. The sources were exhausts from solid propellant motors containing known quantities of beryllium, ranging in quantity from less than one pound to approximately seven pounds of beryllium per release.

A network of approximately 350 air samplers arrayed on ten, 90° radial arcs out to a distance of 2400 meters, sampled the exhaust cloud. The beryllium compounds in the exhaust were used as the tracer material.

The air samplers and sampling techniques used were those which had been used previously at Cape Kennedy and at Vandenberg AFB in support of Projects Ocean Breeze and Dry Gulch[1]. The tracer was collected on membrane filters through which air was drawn at the rate of 3.94 cubic feet per minute. A 3.5 horsepower gasoline engine supplied the power to drive a vacuum pump which maintained somewhat more than one-half atmosphere of pressure differential across a calibrated critical flow orifice, thus providing a constant aspiration rate. The only significant difference between the equipment used in Project Sand Storm and that used for Projects Ocean Breeze and Dry Gulch was a relay fitted to the sampler so that the magneto was grounded when the relay was closed. This permitted the samplers to be shut off from a remote location, as dictated by the toxic nature of the tracer.

Two theodolite tracking cameras were used to track the cloud rise, growth and travel.

A preliminary report of the Project Sand Storm results[5] has been prepared. The final report is in preparation.

Project ADOBE

Project ADOBE is a scaled-up version of Project Sand Storm. Both the motor size, and hence quantity of pollutant released, and the size of the air sampling grid have been increased. Tests with motors releasing

approximately 40 pounds of beryllium have been completed. Tests with motors releasing up to approximately 400 pounds of beryllium are currently underway. Accident simulation tests in which slugs of beryllium will be burned at ambient pressure are included in the program.

The air sampling grid has been expande) 9600 meters. The air sampling system has also been changed from that us in Project Sand Storm. Direct current powered air samplers are being used. A relay on each sampler connected by telephone land lines to a control console in the blockhouse provides a capability for turning the samplers on and off remotely.

The meteorological photo-theodolite tracking system is essentially the same as used in Project Sand Storm.

Project ADOBE was started in September 1964 and is scheduled for completion in the summer of 1966. All tests to this date have been conducted under thermally unstable meteorological conditions.

INDUSTRIAL HYGIENE MONITORING PROGRAM

In-Plant

The in-plant monitoring program consists basically of three elements. First, a series of fixed air sampling locations have been installed within the beryllium test area complex and nearby facilities. The primary purpose of these samplers is to detect any changes in the ambient air quality within the rocket test area complex. A total of nine stations for this purpose are in operation (See Figure 6).

Secondly, specific operations on and around the beryllium test stand are monitored with portable high volume samplers. Sampling has been done on the pad immediately after a test prior to decontamination, following decontamination and while various work operations were being accomplished, e.g., removing motors from the stand, repairing and removing damaged stands and following a motor failure. The primary purpose of this sampling is to determine the degree of respiratory protection required to conduct these operations and the effectiveness of decontamination procedures to reduce contamination to levels which will not require the use of respirators.

The third type of monitoring has been individual monitoring of personnel performing various tasks such as described above, as well as the exposures received by the crew servicing the air samplers on the diffusion

grid. This monitoring is accomplished by means of small air samplers, in which the filter inlet is clipped to a person's lapel and the pump weighing about one pound is attached to a belt or placed in the pocket of his coveralls.

It should be pointed out that respirators are worn by the workmen while personnel are performing such tasks as motor removal, decontamination operations, repairing damaged stands and servicing the diffusion grid air samplers after a test. Thus, much of the data presented herein, represents the potential exposure from these operations without respiratory protection and not the actual exposures received during the programs conducted at AFRPL. The information obtained, however, sheds much light on the potential toxic hazard from testing beryllium motors, and further, can be applied to estimating the potential hazard which may result from other accidents involving the combustion of propellants containing beryllium.

To minimize sample contamination, filter heads are loaded with filters in the laboratory and are transported to the field in self-sealing plastic bags.

With the exception of the lapel samplers, the instrument flow rates are calibrated with a Venturi meter. The lapel samplers are calibrated with a liquid displacement chamber-type calibration instrument designed and built at AFRPL.

Neighborhood.

Five air samplers (Filtronics CF 750's) air samplers have been installed at fixed locations about the perimeter of AFRPL and in Boron, California. These samplers are operated 12 hours per day (10:00 A. M. to 10:00 P. M.) and are changed twice weekly. During Project Sand Storm (1963), these samplers were operated 24 hours per day, except weekends and were changed daily. They are used primarily to monitor any change in the ambient air quality and to compare with current hygienic standards.

ANALYTICAL METHODS

The beryllium air and surface samples are analyzed in the AFRPL Chemical and Materials Laboratory. (Additional help has also been obtained from the Air Force Regional Environmental Health Laboratory, Kelly AFB.) The AFRPL Chem Lab uses the Morin fluorometric method of analysis.[6, 7, 8] The Kelly AFB Lab uses a spectrophotometric technique.

ENVIRONMENTAL SAMPLING DATA

Field Diffusion Results

The results of the field diffusion experiments are summarized in Figure 2. The peak exposure in microgram seconds per cubic meter is normalized to the source strength in a microgram of beryllium to permit evaluation of different release quantities. The P_{50} and P_{95} curves represent the results obtained from Project Sand Storm. The equations for these curves are shown in the legend, and are as follows:

$$X_{50} = 0.238 \ (E_p/Q)^{-0.667}$$

$$X_{95} = 0.305 \ (E_p/Q)^{-0.721}$$

X = Distance from source in meters.

E_p = Peak exposure in microgram-seconds per cubic meter.

Q = Source strength in micrograms.

Sub $_{50}$ & $_{95}$ = Represents the 50th and 95th percentile value. In short, the P_{95} probability curve predicts that 95% of the time the values of E_p/Q found at distance X will be less than indicated and similarily for P_{50} that E_p/Q will be less 50% and greater 50% of that indicated at a given distance X.

The range of peak values for Project Sand Storm is also shown in Figure 2. It can also be seen that the values so far obtained from Project ADOBE are within the range observed during Sand Storm and in general are lower.

As can be seen, considerably more research is required to predict with any accuracy, the downwind dilution of rocket exhaust. We are able, however, at this time to safely predict those distances at which a given exposure will not be exceeded with some degree of confidence.

Perimeter Air Sampling Stations

The location and average concentrations of beryllium at the fixed perimeter air sampling stations since Project ADOBE started are given in Figure 3. The average concentration of samples taken at Station P-3 during February 1965 slightly exceeded the 0.01 micrograms per cubic meter average but was well below the 0.05 micrograms per meter temporary permissible concentrations for 60 days. The average concentrations found excluding the days static tests were conducted are shown in Figure 4. These results

compare with the average background concentrations measured in 1963 prior to the initiation of beryllium testing which was 1.19×10^{-4} micrograms per cubic meter with a range from less than 7×10^{-5} to 4.3×10^{-3} micrograms per cubic meter.

The monthly average of each of these stations since the start of Project Sand Storm in 1963 are given in Figure 5. There has not been a systematic increase and the averages are in general within the background range.

Fixed In-Plant Samplers

The location and results of the fixed in-plant sampler stations are given in Figure 6 for the period since Project ADOBE started. In general, the average concentrations found are between 10^{-3} micrograms per cubic meter to less than detectable (about 10^{-6} micrograms per cubic meter for the average simple volume). The relatively high average values observed in May 1965 at Stations 1 and 2 cannot be explained at this time. They are heavily influenced, however, by a single sample obtained during the month. Due to the wide variance with the other data obtained over the years at these stations, sample contamination is suspected, but cannot be proven. The concentrations are below permissible levels. Similar results for Stations 1 (1-46A), 2 (1-46B) and 3 (1-46C) obtained during Project Sand Storm are shown in Figure 7.

Diffusion Crew Monitoring

The results of the lapel samplers worn by the diffusion crew during post test recovery operations, i.e., removing sampler heads following a test, are shown in Figure 8. These results are interesting in that they give some idea of the potential toxicity downwind of a beryllium release while moderate activity is taking place. A spurious result is seen on the 2400 meter arc for ADOBE No. 5 with a concentration of 18.6 micrograms per cubic meter recorded. Sample contamination is again suspected due to the wide variance with the other results. Lapel samplers worn on the grid during periods other than post test recovery are essentially negative.

Motor Failure Incident, ADOBE No. 4

On 10 February 1965, a solid rocket motor containing 85 pounds of beryllium was fired. A few seconds after ignition, the forward closure

on the motor burned through. Inasmuch as this event was typical of the type of incidents which can occur in static test operations and possibly be representative of other incidents which might occur in handling solid propellants containing beryllium, a considerable sampling program was initiated to document the resulting contamination.

Approximately three hours following the incident, air and surface samples were obtained in the immediate vicinity of the test pad as shown in Figure 9. The air samplers were positioned at 1.5 meters above the ground. Surface samples were obtained by pressing a one square foot piece of low ash filter paper (Simons Adhesive Products Co., Long Island City, New York) by means of a roller devised by AFRPL. Two passes were made at each sample location. Figure 10 shows the results of these samples. The airborne concentrations are surprisingly low considering that no efforts had been made to decontaminate the area prior to the time the samples were taken. The relationship between the air concentrations and surface concentrations was compared with the studies made by Dunster/9 and Stewart./10 Dunster defines a dispersion constant "K" which is the ratio of the air concentration to the surface concentration in units per meter. He has found the value of "K" to range from 4×10^{-5} to 2×10^{-6} units per meter. The lower value was derived from studies while digging through dusty building rubble and in an inclosed, unventilated space. Stewart reports that a representative value for "K" <u>outdoors</u> is 10^{-6} units per meter under quiscent conditions, and under conditions of moderate activity this factor should be raised by a factor of 10.

The ratios of air to surface concentrations previously shown in Figure 10 have been plotted in Figure 11 and compared with the range reported by Dunster. The results compare favorably with "K" ranging from 8.8×10^{-5} to 3.2×10^{-6} if only the first surface sample pass is considered and 8.8×10^{-5} to 1.06×10^{-6} if both passes are considered as a total surface sample. Six of the eight ratios fall within Dunster's range if the first pass is considered and seven of eight if both passes are considered.

The motor test pad, stand, bunker and ground to about 30 to 40 feet around the pad were decontaminated by hosing with copious quantities of water the following day. Air samples were again taken in the same locations.

The air concentrations found are shown in Figure 12. On 15 February 1965, it was observed that heavy winds (25 to 35 knots) were blowing from the east. Four samples were obtained on the west side of the pad. The results are shown in Figure 13. It can be seen that the decontamination procedures are effective and lasting in surpressing air borne concentration.

On 16 February 1965, the damaged motor case was removed from the stand and was crated and returned to the contractor for repair and re-use. Samples were taken on the pad during this operation and the results are shown in Figure 14. Lapel samplers worn by three members of the crew recorded concentrations of 3.457, 2.895 and 0.850 micrograms per cubic meter. At one sample position, a "respirable" dust sampler (Unico Model 240) was placed immediately beside a high volume sampler. The "respirable" fraction of this sample contained approximately 17% of that found on the "total" concentration found on the high volume sampler.

On 17 February 1965, the damaged stand was removed from the pad and a new stand installed. Samples were again taken during the operation and the results are shown in Figure 15. A lapel sampler worn by a welder, cutting the stand from the pad recorded 1.744 micrograms per cubic meter. A "respirable" dust sample taken during this operation recorded more (2.208 versus 1.877 micrograms per cubic meter) than a high volume sampler at the same location.

The cross wing profiles of cloud exposures from ADOBE No. 4 as it traversed downwind are shown in Figure 16. It is typical in shape, width and relative magnitude of other motor exhaust clouds from similar size and larger size motors (Figures 17 and 18).

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AFRPL BERYLLIUM RELEASE SUMMARY

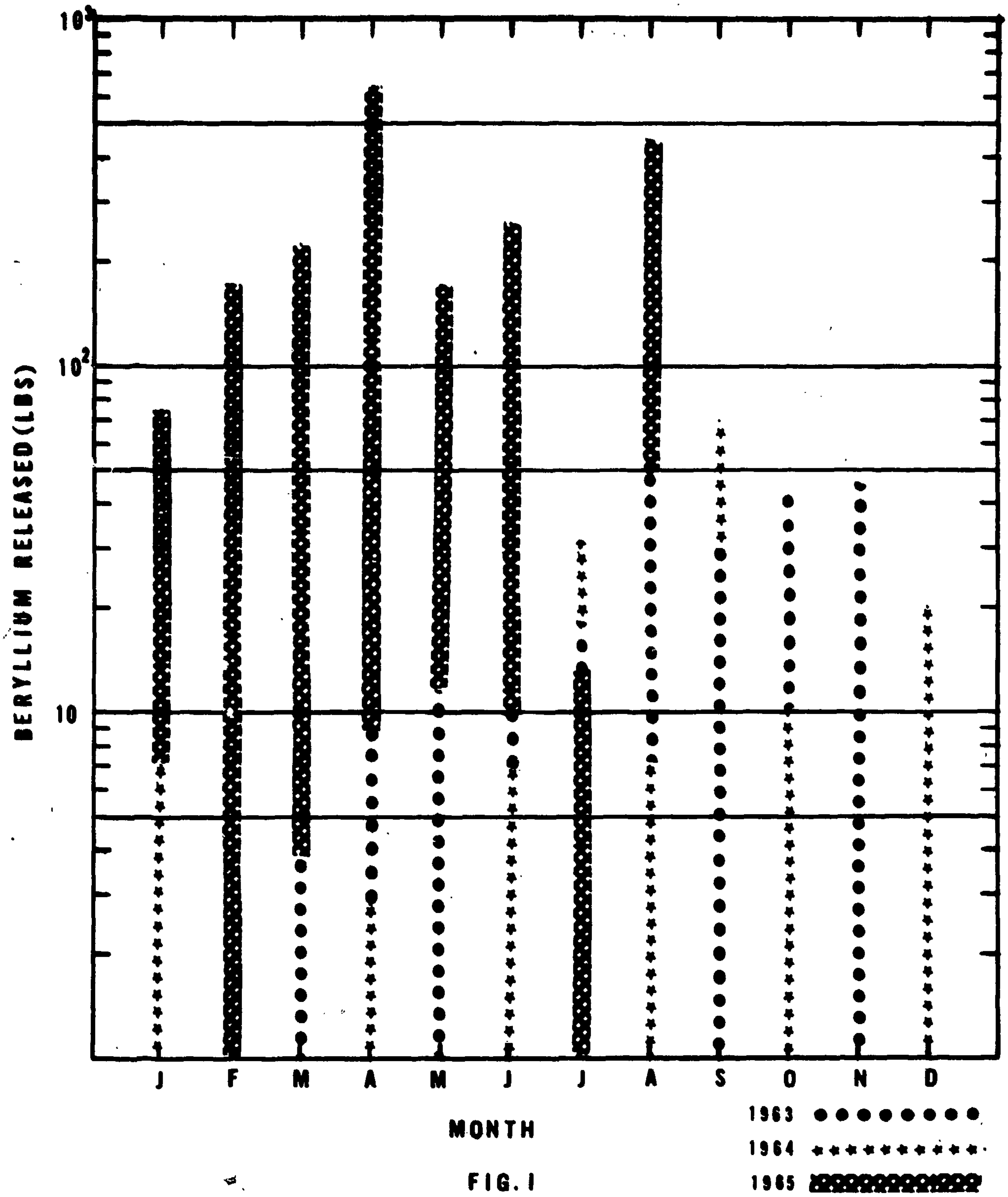

FIG. I

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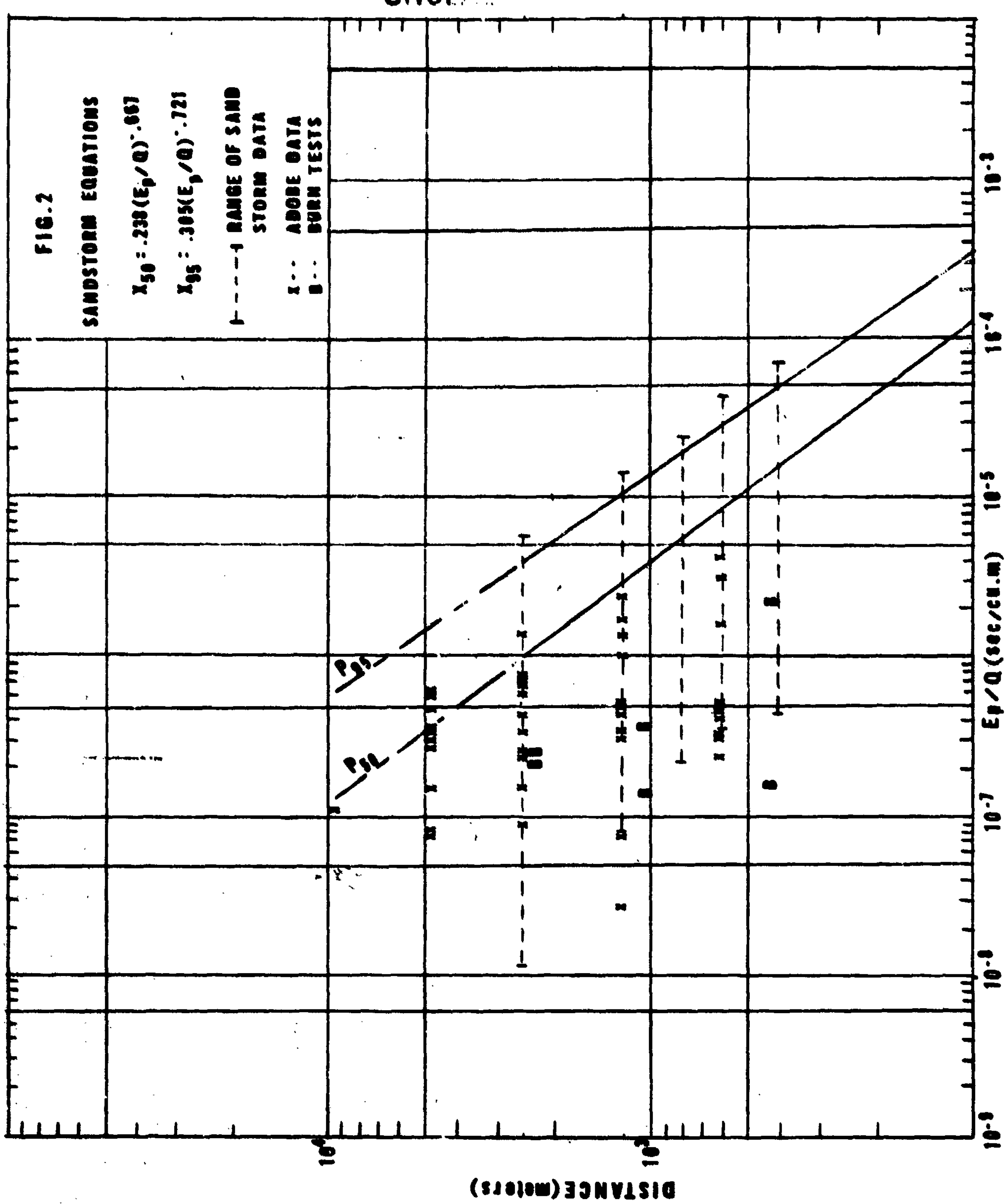

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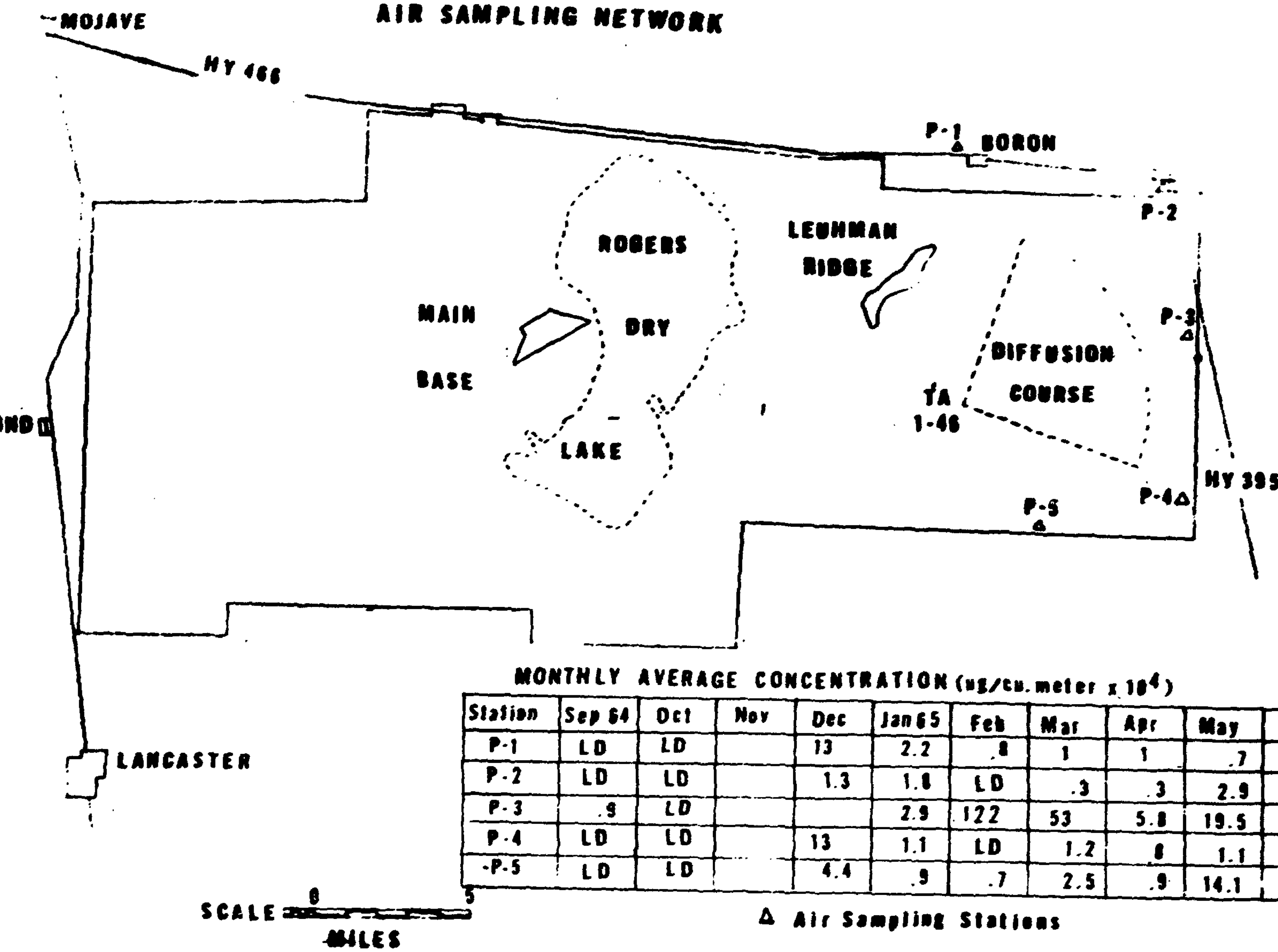
FIG. 3

PERIMETER

AIR SAMPLING NETWORK



MONTHLY AVERAGE CONCENTRATION (ug/cu. meter x 10^4)

Station	Sep 64	Oct	Nov	Dec	Jan 65	Feb	Mar	Apr	May	Jun
P-1	LD	LD		13	2.2	.8	1	1	.7	1.2
P-2	LD	LD		1.3	1.8	LD	.3	.3	2.9	1.3
P-3	.9	LD			2.9	122	53	5.8	19.5	99.1
P-4	LD	LD		13	1.1	LD	1.2	8	1.1	
P-5	LD	LD		4.4	.9	.7	2.5	.9	14.1	1

Δ Air Sampling Stations

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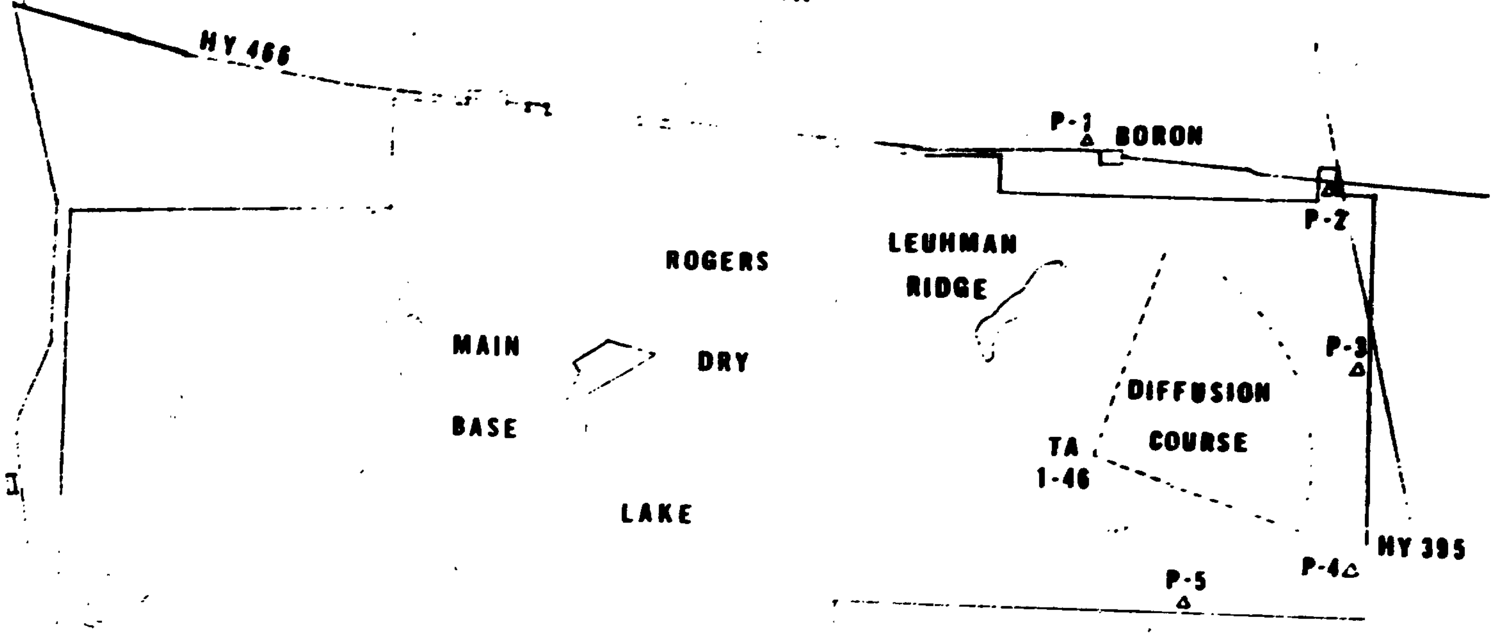
FIG.4

PERIMETER

AIR SAMPLING NETWORK



AVERAGE CONCENTRATION-NON TEST DAYS (ug/cu.meter x 10^4)

Station	Sep 64	Oct	Nov	Dec	Jan 65	Feb	Mar	Apr	May	Jun
P-1	LD	LD	—	31	2.7	2.4	1 7	1.2	.2	LD
P-2	LD	LD	—	LD	2	LD	.4	2	.5	LD
P-3	LD	LD	—	11 9	3 8	.8	.5	.1	.8	.5
P-4	LD	LD	—	LD	1.4	LD	1 5	.1	.3	—
P-5	LD	LD	—	1.5	3 5	LD	.2	.3	.6	LD

SCALE 0 — 5
MILES

Δ Air Sampling Stations

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FIG. 5

BERYLLIUM AIR SAMPLING

PERIMETER STATIONS – 1963 – 1965

ug/cu.m. x 10^4

MONTH	P-1			P-2			P-3			P-4			P-5		
	63	64	65	63	64	65	63	64	65	63	64	65	63	64	65
JAN			2.2			1.8			3.0			1.1			0.9
FEB			0.8			0			122			0			0.7
MAR	9.4		0.1	15.6		0.3	10.3		53.0	11.9		1.2			2.5
APR	11.2		0.1	8.5		0.4	12.7		5.8	8.3		0.8	5.4		1.0
MAY	1.1		0.7	1.9		2.4	2.7		19.5	1.2		1.1	0.3		14.1
JUN	9.1		1.2	0.6		1.3	1.8		99.1	18.7		0.2	1.4		0
JUL	38.5			0.9			1.5			12.1			0.6		
AUG	3.4			12.1			0.4			0.1			0.1		
SEP	19.2	0		0.3	0		0.2	0.9		0.2	0		0.2	0	
OCT	1.4	0		0.5	0		19.3	0		1.8	0		6.0	0	
NOV	2.4			0.2			12.2			7.0			10.8		
DEC		12.7			0.1			69.1			13.1			4.4	

BACKGROUND – 1.19 x 10^{-4} ug/cu.m

RANGE – <7 x 10^{-5} TO 4.3 x 10^{-3} ug/cu.m.

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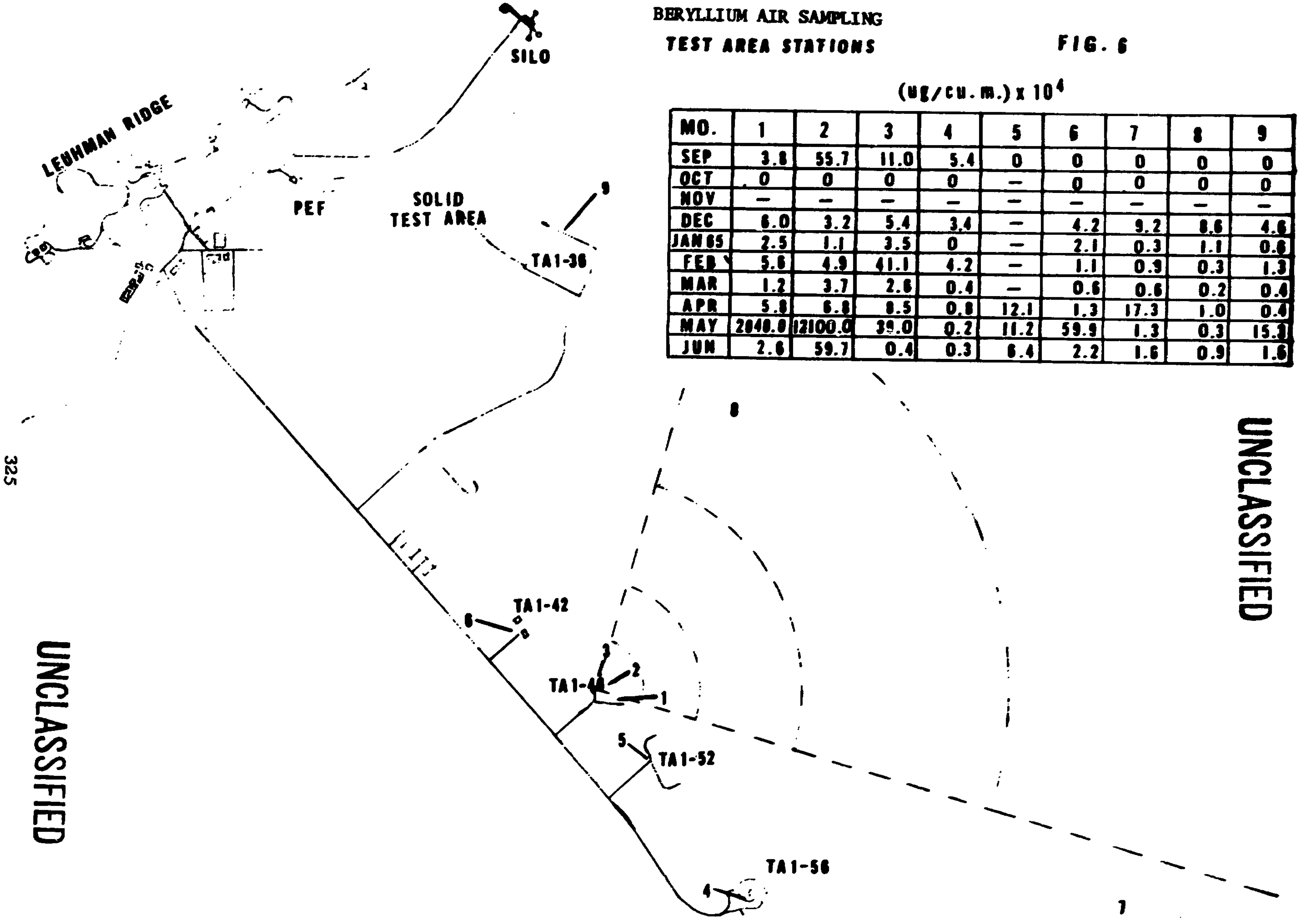
BERYLLIUM AIR SAMPLING
TEST AREA STATIONS

FIG. 6

(ug/cu. m.) x 10^4

MO.	1	2	3	4	5	6	7	8	9
SEP	3.8	55.7	11.0	5.4	0	0	0	0	0
OCT	0	0	0	0	—	0	0	0	0
NOV	—	—	—	—	—	—	—	—	—
DEC	6.0	3.2	5.4	3.4	—	4.2	9.2	8.6	4.6
JAN 65	2.5	1.1	3.5	0	—	2.1	0.3	1.1	0.8
FEB	5.6	4.9	41.1	4.2	—	1.1	0.9	0.3	1.3
MAR	1.2	3.7	2.6	0.4	—	0.6	0.6	0.2	0.4
APR	5.8	6.8	8.5	0.8	12.1	1.3	17.3	1.0	0.4
MAY	2040.0	12100.0	39.0	0.2	11.2	59.9	1.3	0.3	15.3
JUN	2.6	59.7	0.4	0.3	6.4	2.2	1.6	0.9	1.6



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GENERAL AIRBORNE CONCENTRATIONS OF BERYLLIUM

1-46 TEST AREA

PROJECT SANDSTORM

MONTH	1-46A		1-46B		146C		CONTROL ROOM		CHANGE HOUSE	
	RANGE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE
MARCH	0 - .00917	.00422	0 - .05556	.00385	0 - .02536	.00730	0 - .01429	.00339	0 - .02042	.00724
APRIL	0 - .01227	.00173	0 - .01412	.00204	0 - .01000	.00085	.00201 .01458	.00964	0 - .01661	.00487
MAY	0 - .05357	.00060	0 - .00628	.00056	0 - .00783	.00099	-	-	.00291 .00474	.00432
JUNE	0 - .04706	.00150	0 - .00684	.00108	0 - .00749	.00046	-	-	-	-
JULY	0*	0*	0 - .00114	.00016	0 - .00686	.00071	-	-	-	-
AUGUST	-	-	0 - .00552	.00128	0 - .01900	.00071	-	-	-	-
SEPTEMBER	*	-	0 - .07515	.00241	0 - .00872	.00102	-	-	-	-
OCTOBER	0 - .00610	.00034	-	-	0 - .01322	.00088	-	-	-	-
NOVEMBER	0 - .00131	.00049	-	-	0 - .00147	.00034	-	-	-	-
SUMMARY		.00083		.00126		.00089		.00634		.00563

FIG. 7

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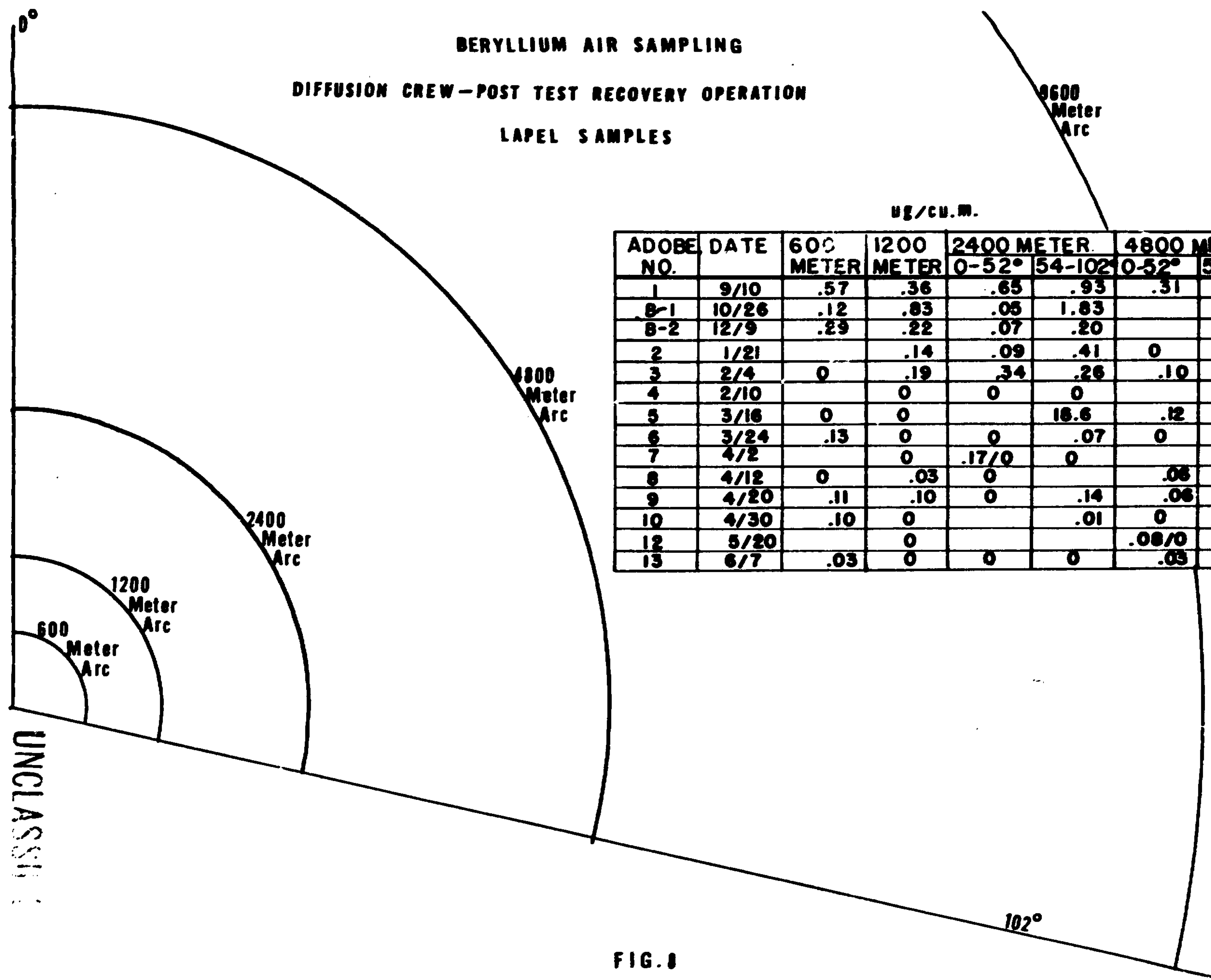
BERYLLIUM AIR SAMPLING

DIFFUSION CREW—POST TEST RECOVERY OPERATION

LAPEL SAMPLES



ug/cu.m.

ADOBE NO.	DATE	600 METER	1200 METER	2400 METER 0-52°	2400 METER 54-102°	4800 METER 0-52°	4800 METER 54-102°
1	9/10	.57	.36	.65	.93	.31	4.29
B-1	10/26	.12	.83	.05	1.83		
B-2	12/9	.29	.22	.07	.20		
2	1/21		.14	.09	.41	0	0
3	2/4	0	.19	.34	.26	.10	
4	2/10		0	0	0		0
5	3/16	0	0		16.6	.12	
6	3/24	.13	0	0	.07	0	.03
7	4/2		0	.17/0	0		.12
8	4/12	0	.03	0		.06	0
9	4/20	.11	.10	0	.14	.06	.06
10	4/30	.10	0		.01	0	0
12	5/20		0			.08/0	
13	6/7	.03	0	0	0	.03	0

FIG. 8

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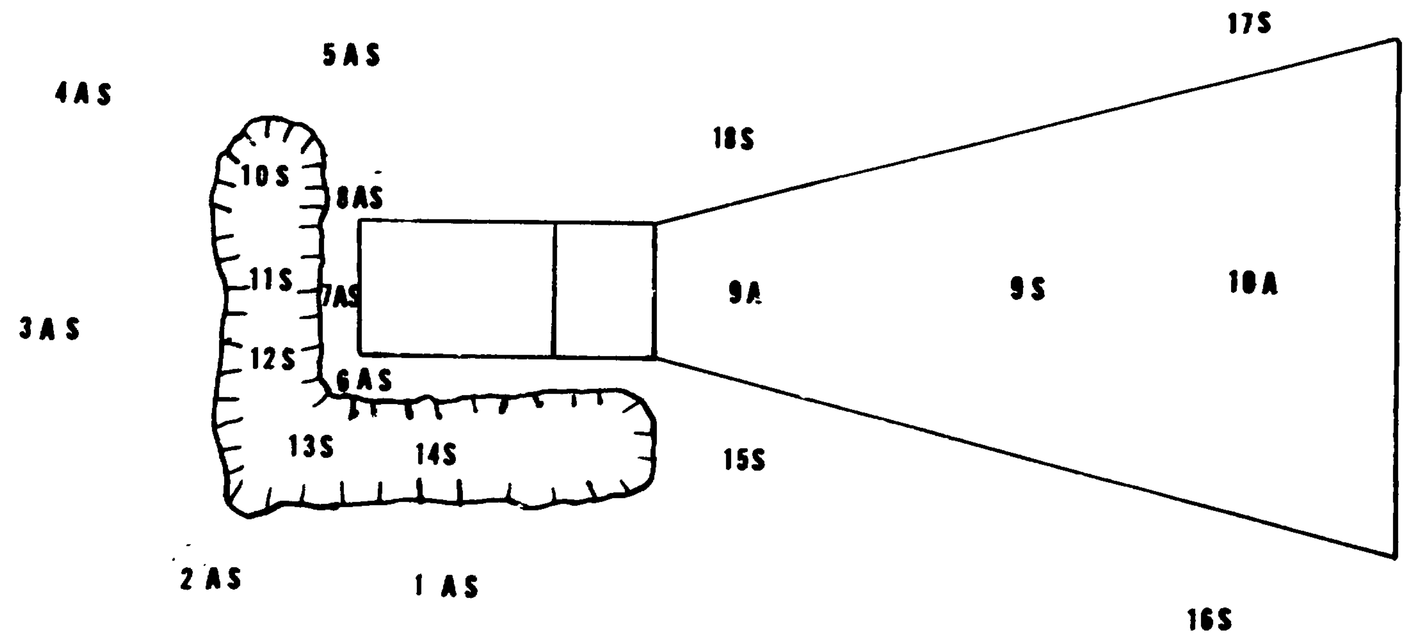
BERYLLIUM AIR SAMPLING
TEST STAND 1-46C-1



A—AIR SAMPLER
S—SOIL SAMPLE

FIG. 9

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BERYLLIUM SAMPLING

AT TEST STAND FOLLOWING ADOBE 4 FAILURE

LOCATION	SURFACE CONCENTRATION (ug/sq. m.) 1ST PASS	2ND PASS	AIR CONCENTRATION (ug/cu.m)
1	8,426	17,057	0.027
2	882	1,157	0.030
3	306	469	0.027
4	SAMPLE LOST	387	0.014
5	9,688	20,699	0.079
6	702,889	1,226,127	4.848
7	224,214	608,166	2,452
8	78,361	94,917	4.184
9 9,257	9,257	19,827	7.951
10	11,033	48,061	5.239
11	230,995	278,357	
12	339,819	356,880	
13	13,713	716,603	
14	210,651	266,840	
15	34,918	118,985	
16	23,680	213,988	
17	72,657	133,474	
18	17,459	540,697	

LAPEL SAMPLERS ON SAMPLING CREW RECORDED 2.88 and 5.28 ug/cu.m.

FIG. 10

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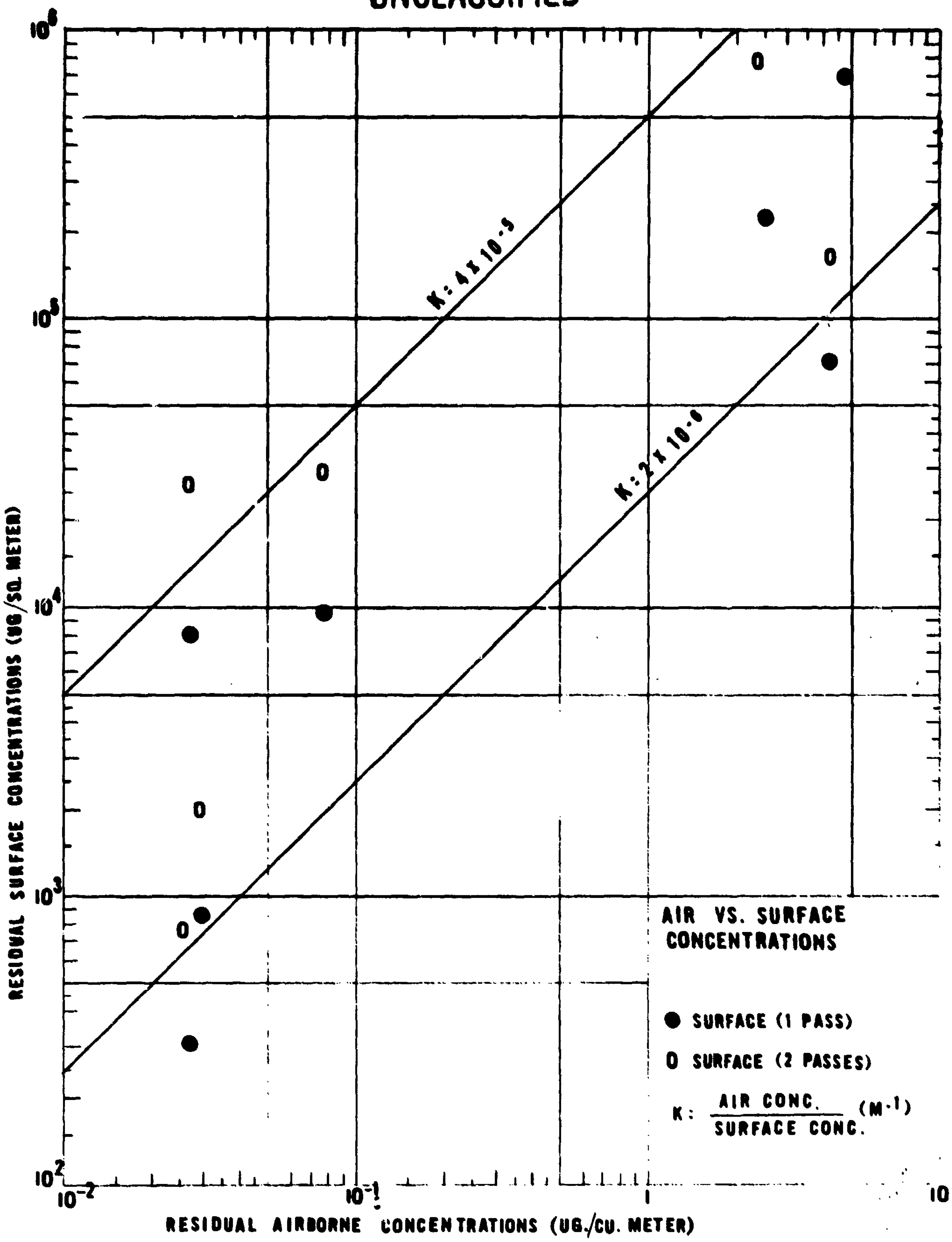

FIG. 11

FIG.12 UNCLASSIFIED

BERYLLIUM SAMPLING RESULTS

PRE-AND POST-DECONTAMINATION SAMPLES

FOLLOWING 11 FEB 65 MOTOR FAILURE

POSITION	CONCENTRATION (ug/cu.m.) PRE-DECONTAMINATION	CONCENTRATION (ug/cu.m.) POST-DECONTAMINATION
1	.027	.011
2	.030	.042
3	.027	.063
4	.014	.085
5	.079	.051
6	4.848	.058
7	2.452	.000
8	4.184	.074
9	7.951	.041
10	5.239	.061

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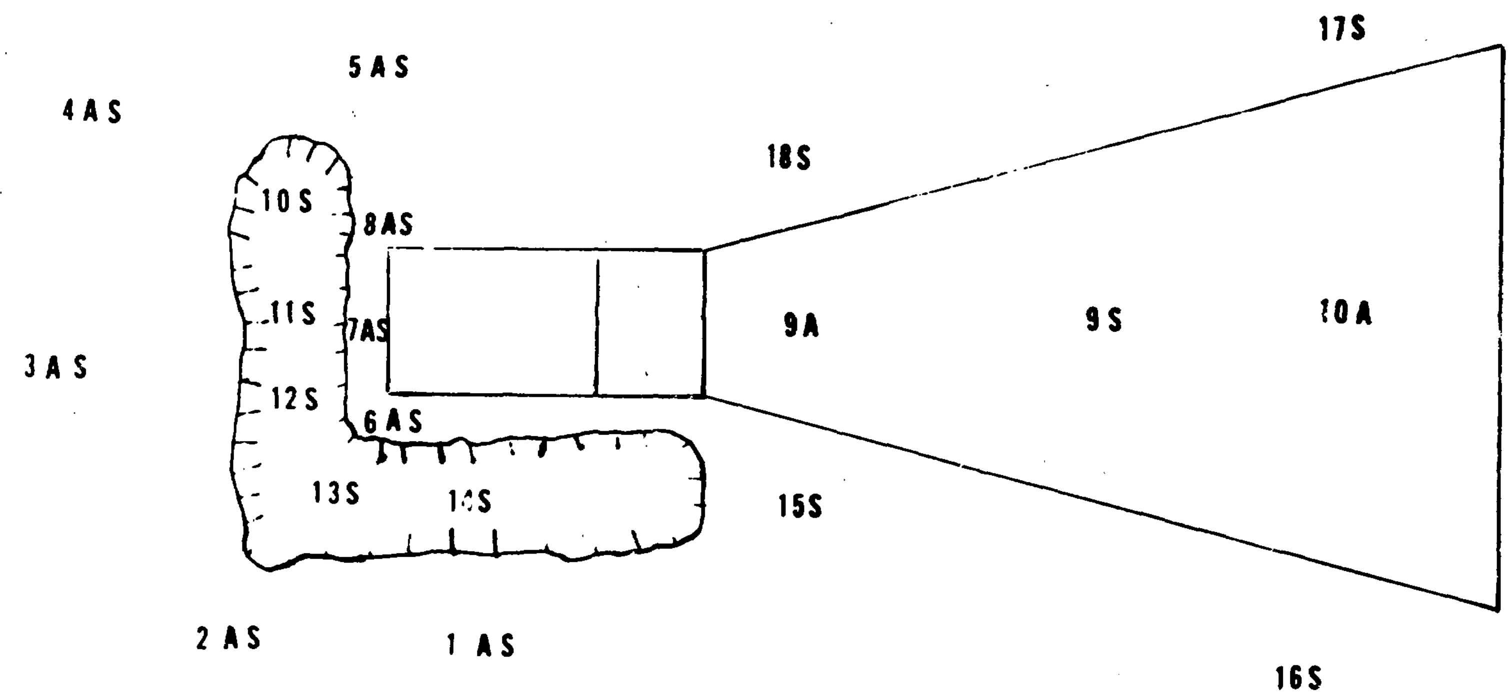
BERYLLIUM AIR SAMPLING
TEST STAND 1-46C-1



A—AIR SAMPLER
S—SOIL SAMPLE

FIG. 13

Beryllium Motor Testing Sampling Results Air samples at 5 days following 11 Feb 65 Motor Failure 25-35 knot winds from the East		
Position	Date	ug Be/cu.Meter
6	15 Feb 65	0.020
8	15 Feb	0.006
11	15 Feb	0.082
12	15 Feb	0.033

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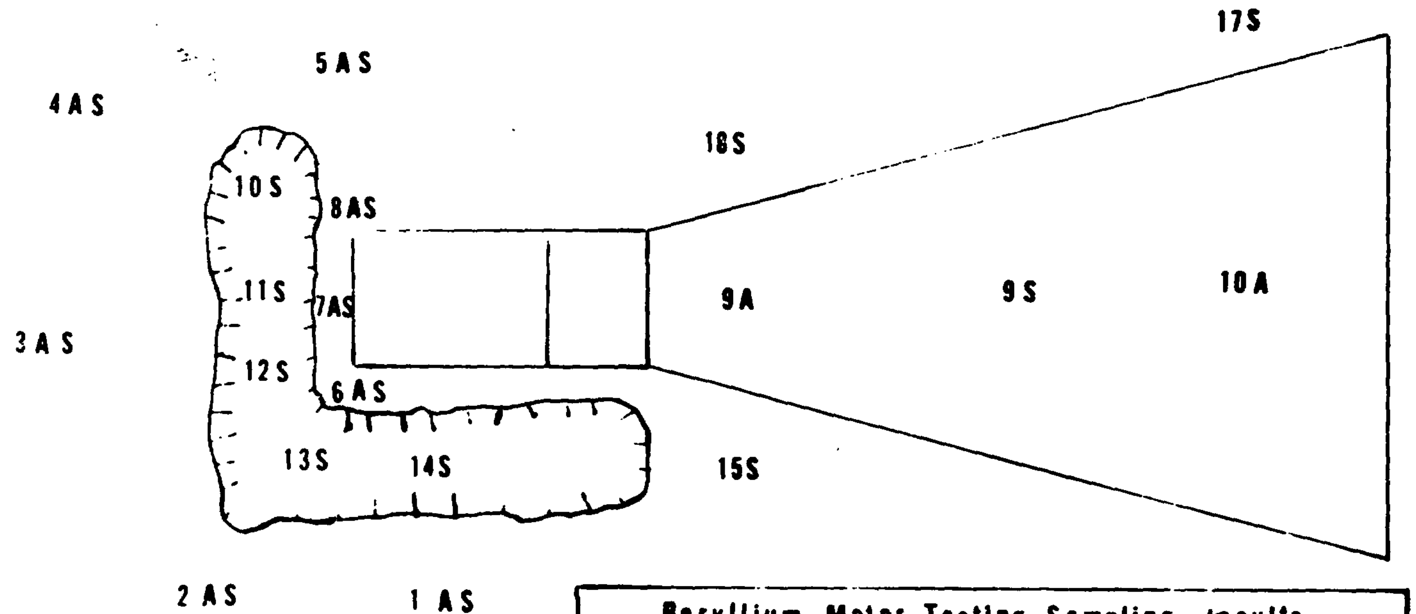
BERYLLIUM AIR SAMPLING
TEST STAND 1-46C-1



A—AIR SAMPLER
S—SOIL SAMPLE

FIG.14

Beryllium Motor Testing Sampling Results Removing ADOBE 4 Motor From Stand

Position	Date	ug Be/cu. Meter
6	16 Feb	0.070
7	16 Feb	0 955
8	16 Feb	0.481
9	16 Feb	1.408
9'	16 Feb	0.237

Lapel samplers worn by crew recorded 3.457, 2.895, & 0.850 ug Be/cu. Meter.

'Duplicate sample taken at position 9 with Unico Model 240 Respirable Dust Sampler. Concentration given represents the portion retained on filter i.e. "Respirable" fraction.

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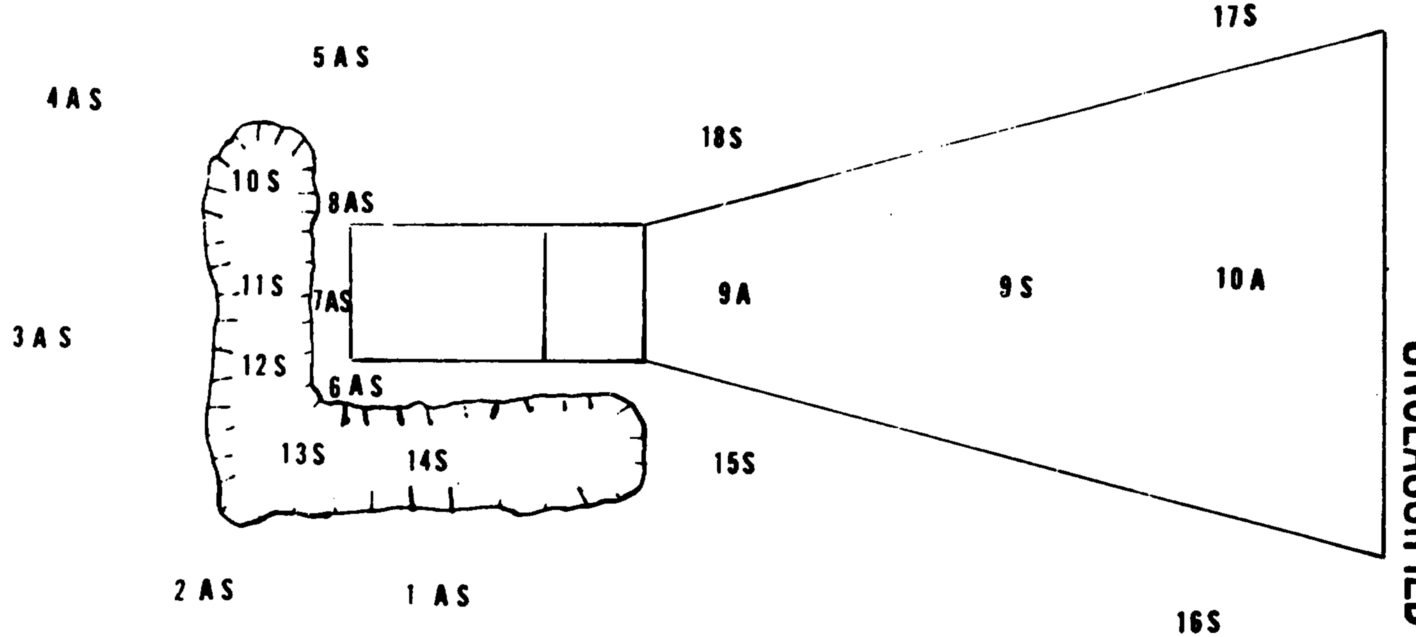
BERYLLIUM AIR SAMPLING
TEST STAND 1-46C-1



A–AIR SAMPLER
S--SOIL SAMPLE

FIG.15

Beryllium Motor Testing Sampling Results Removing Damaged Stand & Installing New Stand		
Position	Date	ug Be/cu. Meter
6	17 Feb 65	0.288
7	17 Feb	1.877
7'	17 Feb	2.208
8	17 Feb	0.433

'"Respirable" Dust Sample
Lapel Sampler worn by welder cutting stand from pad recorded 1.744 ug Be/cr Meter.

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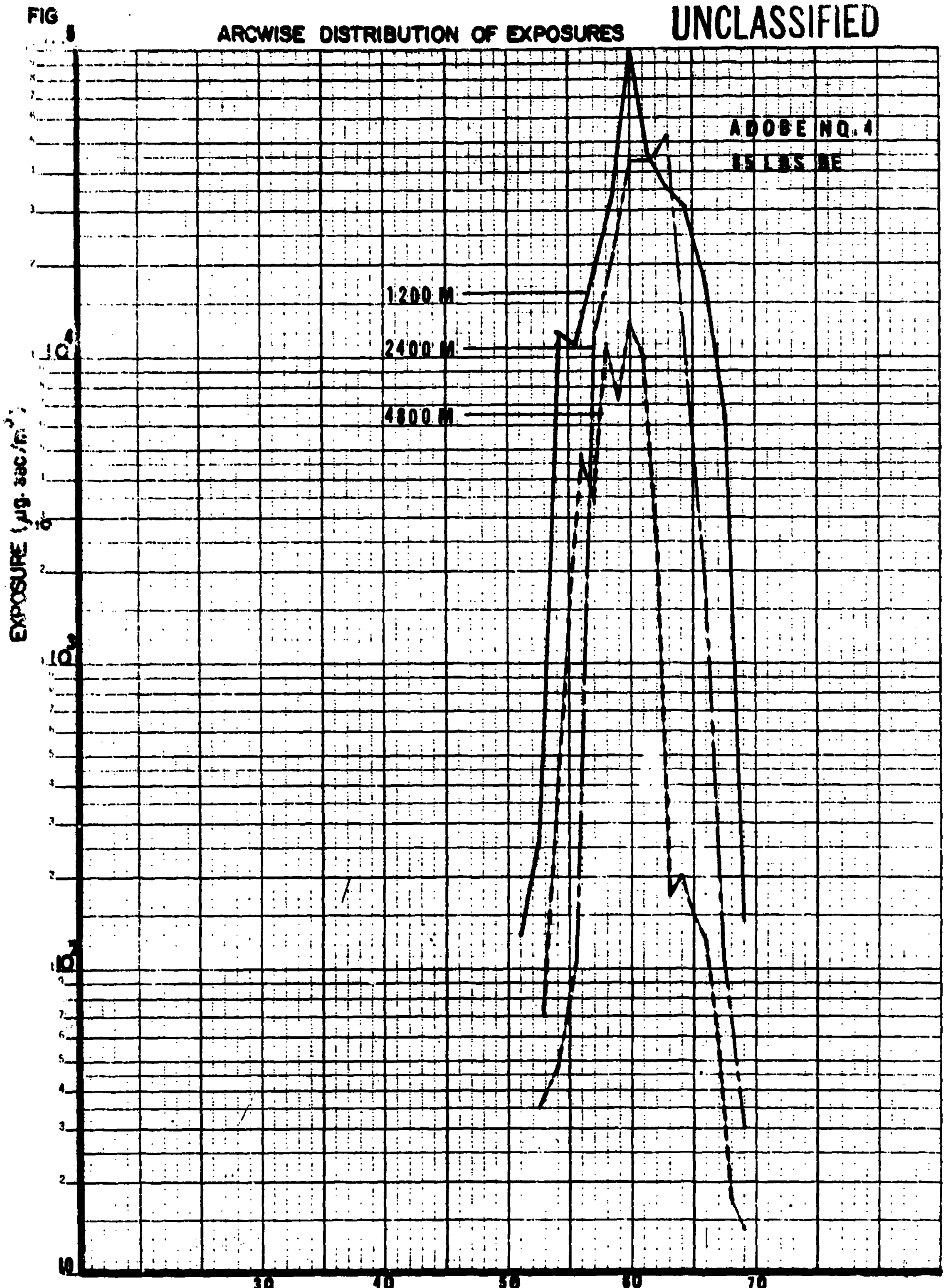

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FIG. 16

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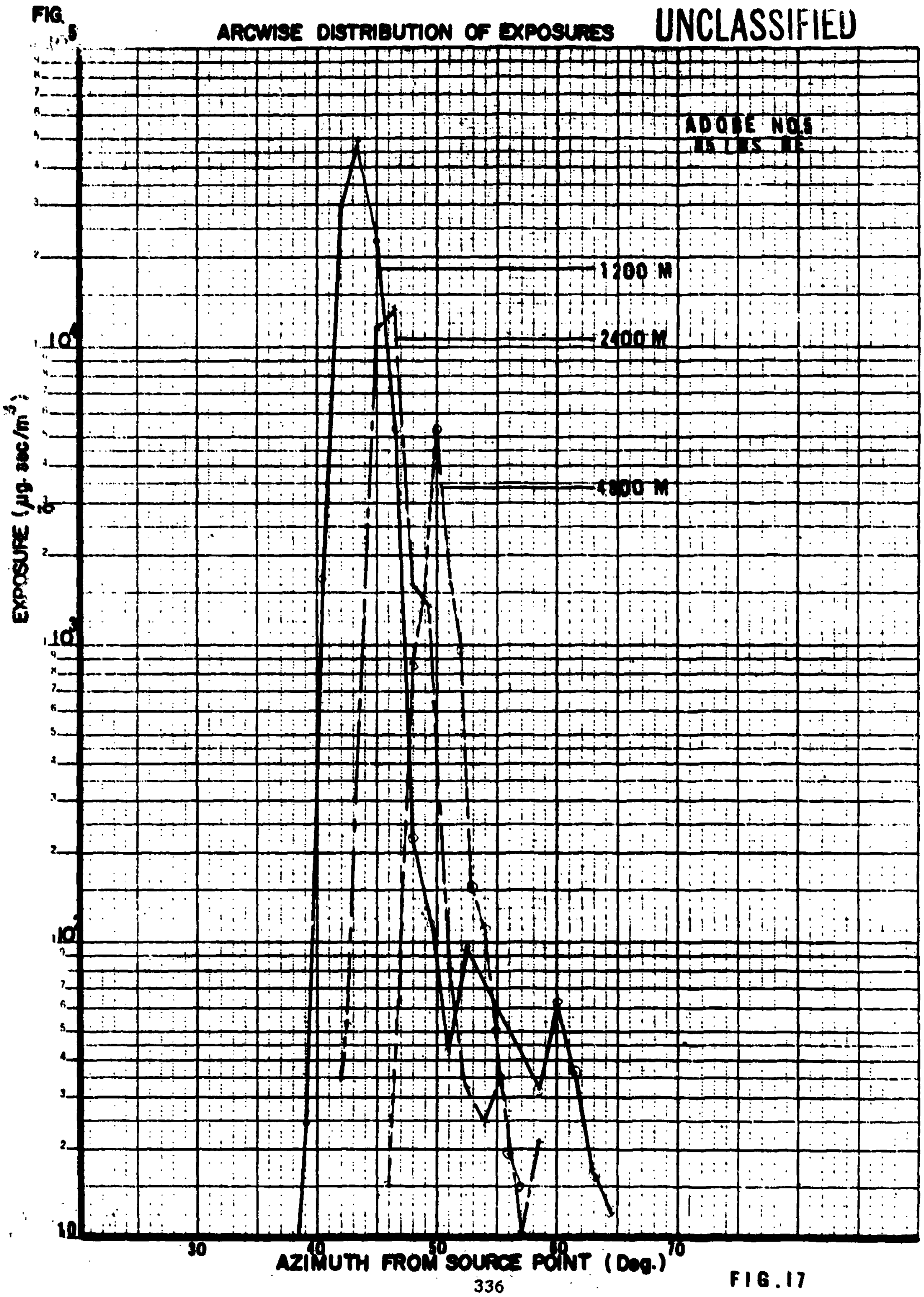

FIG. 17

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FIG.

ARCWISE DISTRIBUTION OF EXPOSURES UNCLASSIFIED

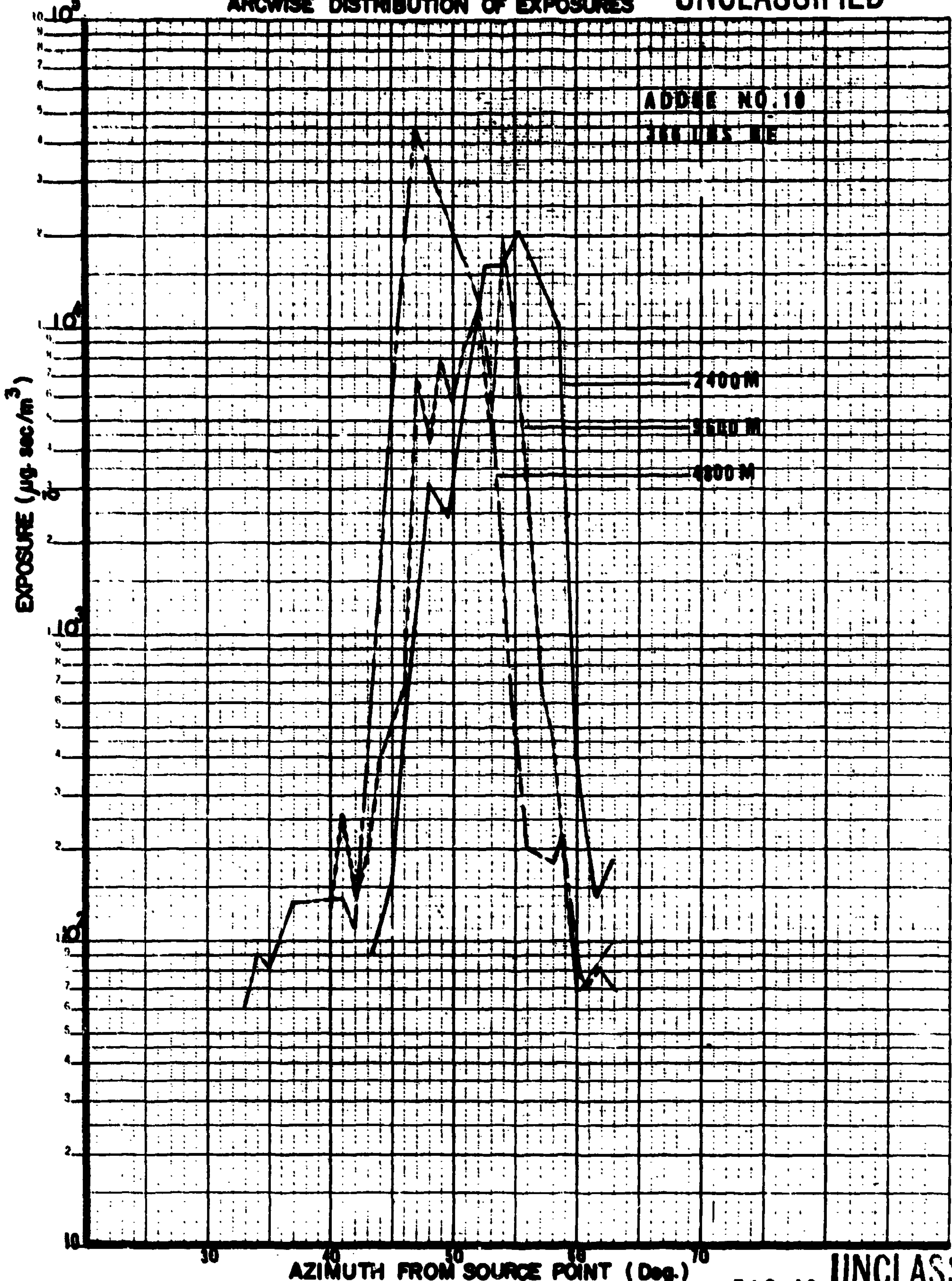

FIG. 18 UNCLASSIFIED

MONITORING OF ENVIRONMENTAL DISPERSION OF BERYLLIUM FROM DISPOSAL OF A SOLID PROPELLANT BY TRENCH BURNING AT DUGWAY PROVING GROUND, UTAH

Maj. Lee C. Herwig, USA
U. S. Army Environmental Hygiene Agency
Edgewood Arsenal, Md.

Because of its lightness, its ability to absorb and conduct heat rapidly, and other favorable factors, the use of beryllium is being applied in many operations. Included is its use as a component of missile propellants, in which it has been shown to produce a significant increase in specific impulse and consequently in missile performance.

However, after a period of time propellant fuel may deteriorate or crack in the engine, or for other reasons, disposition of it may have to be made. Additionally, toxic wastes including propellant, handling materials, and protective respirators are produced in laboratories and on the production line and require special disposal techniques. Significant quantities of these materials have been generated by Air Force civilian contractors located in the vicinity of Salt Lake City, Utah. In 1963, an agreement was reached between the U.S. Air Force and Dugway Proving Ground, Utah, in which the latter accepted a contract to dispose of a given quantity of this propellant waste. As a result, shipment began in August of that year and by April 1965, 42,000 pounds of propellant waste were on site at Dugway. Further deliveries during the summer of 1965 ran the total to 50,000 pounds of waste, of which it was estimated that 300 pounds of beryllium metal were present.

While much information concerning the toxicity of beryllium has been collected, the nature and the extent of the hazard associated with its use under a wide variety of conditions are still controversial. However, historically, the use and handling of the metal and its compounds has caused an appreciable number of serious illnesses, and, therefore, the injurious effects of contact with and absorption of these substances are matters of deep concern.

Because of this situation both civilian and military authorities were concerned about the proposed disposal by burning of such a large quantity of beryllium, and as a result, a joint meeting of representatives of the U. S. Air Force and U. S. Army Surgeons General was held during April 1965. It was decided by this group that the US Army Environmental Hygiene Agency would serve as a lead activity in development of, and carrying out an environmental survey, prior to, during, and following disposal of the beryllium waste at Dugway.

The study would be conducted as an R&D project and would be funded by the Medical R&D Command, with Colonel Robert G. McCall and Lt Colonel Alois Peeznik, Directors, Engineering Services and Medical Services, USAEHA, respectively, as principal investigators, and Maj. Lee C. Herwig as Surgeon General's Project Officer. Analytical support, technical assistance and a large portion of the sampling equipment was to be furnished by the US Air Force. The Regional Environmental Health Laboratory at Kelly Air Force Base, Texas, commanded by Col. Walter Melvin, would perform all the chemical analyses, and Capt. Owen Kittilstad, a recognized authority on beryllium dispersion at the Edwards Rocket Propulsion Lab, was appointed to serve as Air Force Technical Coordinator.

Mr. Pope A. Lawrence, Chief, Federal Agencies Section; Mr. Austin Heller, Deputy Chief, Technical Services Branch; and Mr. Paul Humphries, Chief Meteorologist, all of the Division of Air Pollution, USPHS, acted as technical consultants, providing extremely valuable assistance in the preparation of the final protocol which was designed with a singleness of purpose, the protection of the health and welfare of residents in the vicinity of Dugway.

Dr. C. D. Carlyle Thompson, Director of Public Health, and Dr. Grant S. Winn, Utah State Health Department, offered their full cooperation in this project. An agreement was reached between the State and the Agency whereby replicate sampling would be accomplished. Mutual sampling points were serviced by State personnel during the week, and by Agency personnel on weekends.

Col. Stone, Commanding Officer, Dugway Proving Ground, named Mr. Bob Alg, Safety Director at DPG, as test control officer and pledged full support of all facilities at his installation in support of this operation.

The objectives of the test were then:

(1) To insure the health and safety of civilian and military personnel through safe disposal of the beryllium, <u>and</u>

(2) To determine the distribution of beryllium to the environment at predesignated inhabited or potentially occupied locations.

No attempt was made during this study to determine new or evaluate existing hygienic criteria with respect to beryllium. The criteria specified by the US Air Force to their contractors, which parenthetically, are basically a restatement of the original AEC recommendations, were used as our guide to interpretation of our data.

Dugway Proving Ground is located in a semi-arid of western Utah (see view graph #1). Salt Lake City is in the center of the Great

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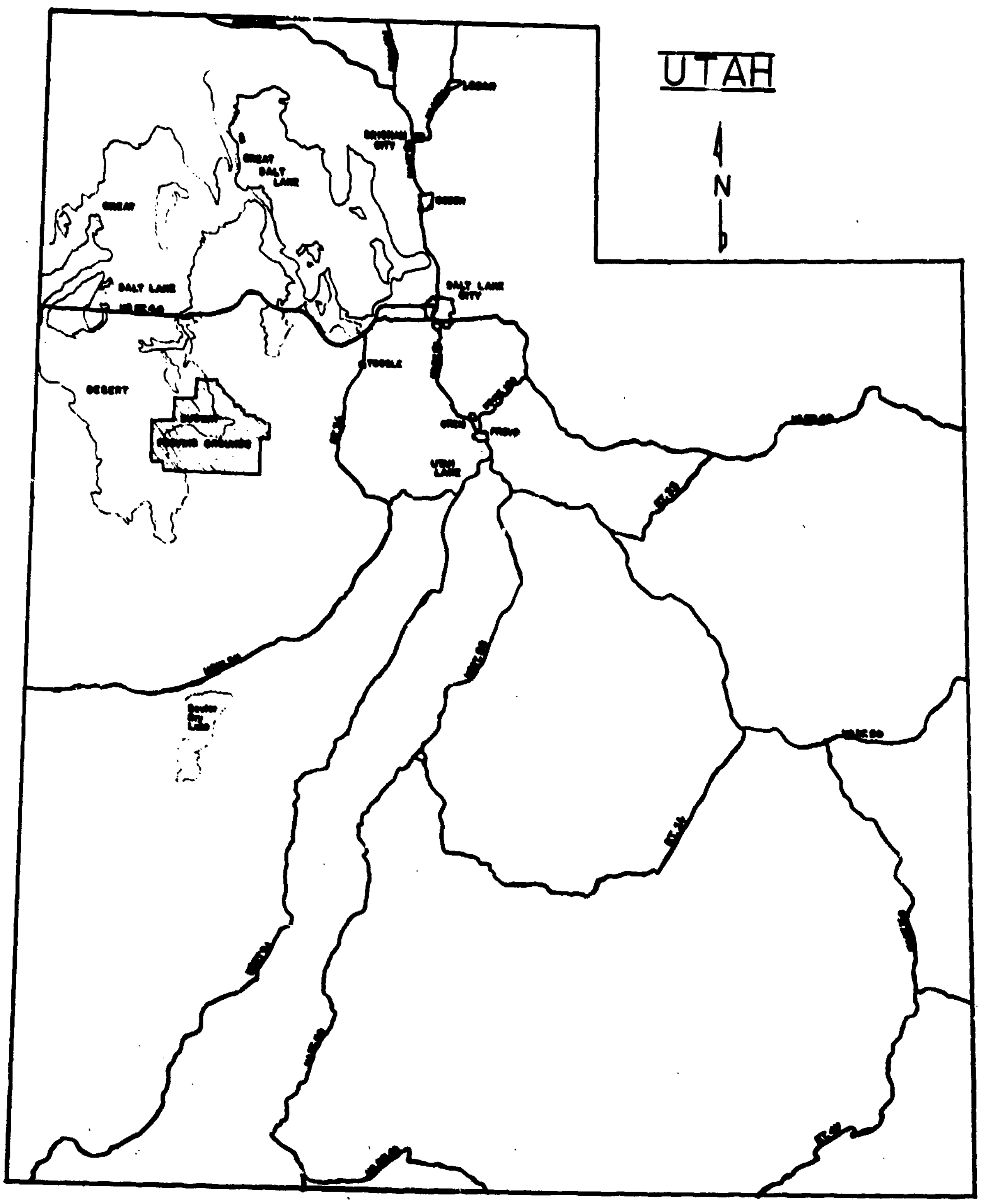

VIEW GRAPH NO. 1

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Salt Lake Valley and is 80 miles northeast of Dugway. Dugway is bounded on three sides by mountain ranges and on the fourth by the Great Salt Lake Desert.(see view graph #2). The population density in the area is extremely low. Civilian communities are located at Wendover Knolls and Delle, north of Dugway, and Callao and Fish Springs, south of Dugway. Knolls and Delle each consist of a filling station and restaurant along US Route 40 which at its nearest point is approximately 40 miles north of Dugway Proving Ground. Callao is a cluster of some four ranches on the Nevada border southwest of Dugway.

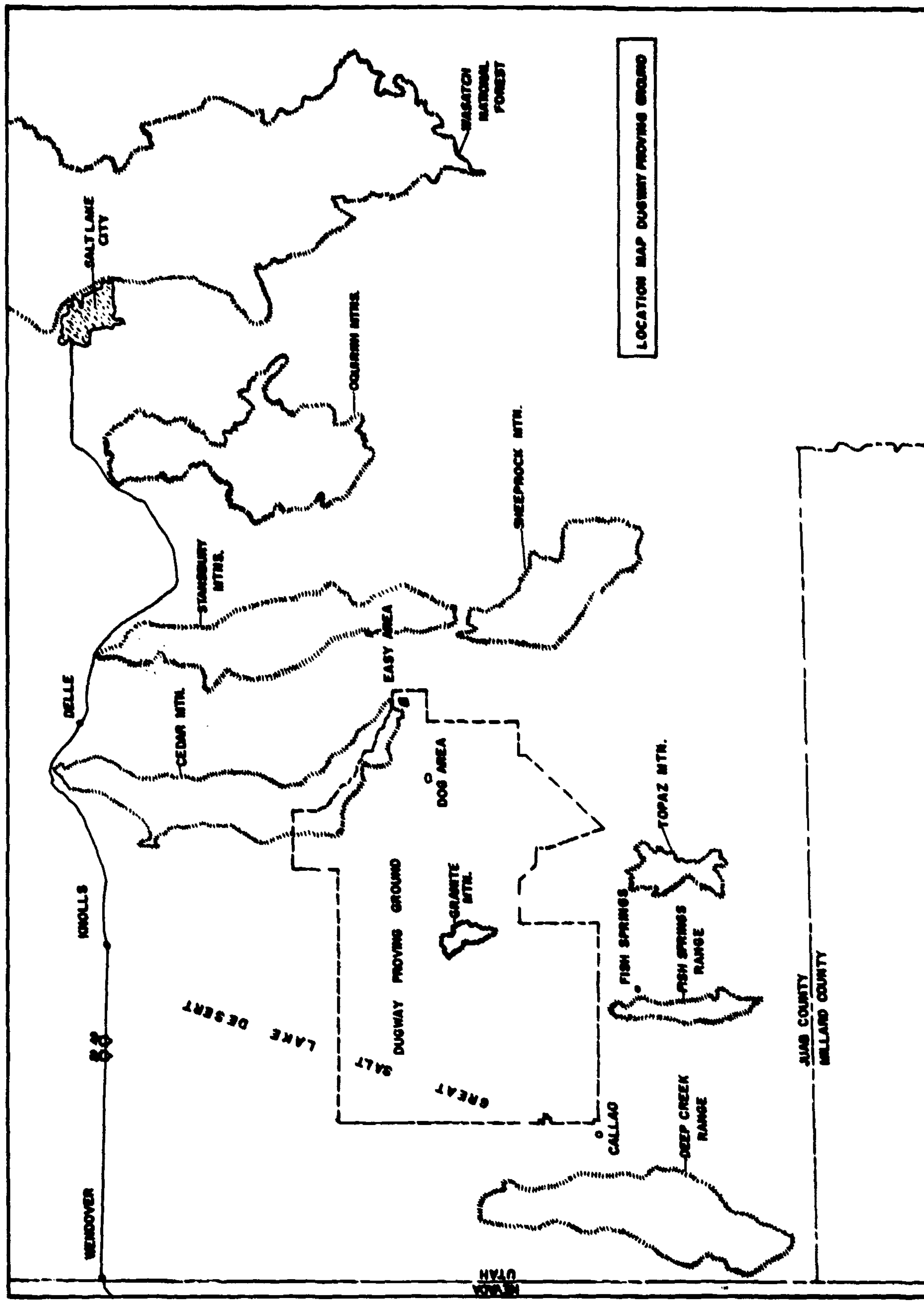
In addition to Dugway Proving Ground, the greatest portion of this area of Utah is comprised of the Wendover Bombing Range, a currently inactive Air Force installation.

There is mining activity in the area south of Dugway and there are reported to be large deposits of a rather low-yield beryllium fluorosilicate ore. Our flight over this area revealed some exploratory core drilling but no production. The potential additions that mining might add to natural background concentrations is obvious. While no conclusions were reached concerning this factor, we were able to pinpoint for the State of Utah the active operations in this area and they are initiating studies of background in the vicinity of Topaz Mountain.

The site of the propellant waste disposal itself was Granite Mountain, a peak extending some 3000 feet above the 4000 foot valley floor. It is located on the western range at Dugway Proving Ground 30 miles due west of the Main Dugway post (Easy Area), and 20 miles west of the Technical Operations Area (Dog Area). Wendover is 60 miles across the salt flats to the northwest of the mountain and the four families at Callao are 30 miles to the southwest of Granite Peak.

The disposal area is located in a canyon on the northeast tip of the mountain. The ridge to the north of the canyon is approximately 300 feet above the canyon floor. There are two trenches containing the waste material, one parallel to the ridge and approximately 200 feet long. The second is perpendicular to the ridge and approximately 100 feet long.

Air sampling was accomplished at the occupied and inhabited areas previously shown using ten General Metal Works high-volume (50-70 cfm) samplers enclosed in an aluminum shelter. (See view graph #3) They were operated continuously and were shut down once a day only in order to change the filter paper. They were set in operation about ten days prior to the burn in order to determine background beryllium concentrations. They were all operated from line current, with the exception of the samplers at Callao and the one located on Stark Road which were operated from generators. These samplers continued to operate for a week after the burn.



VIEW GRAPH NO. 2

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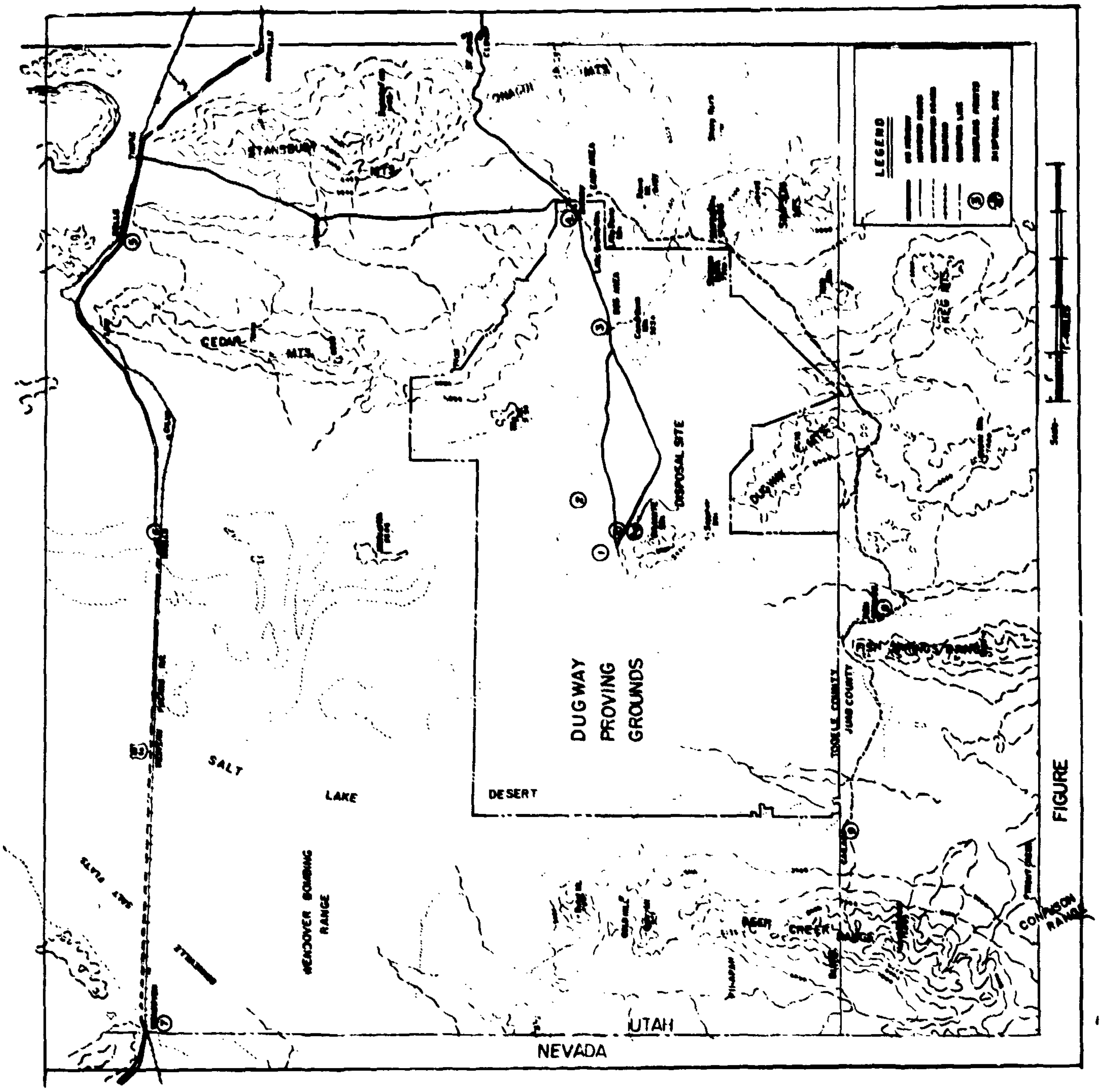

VIEW GRAPH NO. 3

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The other air sampling (i.e., the sampling to determine the local dispersion pattern) was done using 35 Staplex and Gelman battery-operated samplers with a sampling rate from 3-15 cfm. (see view graph #4) These samplers were located to the north of the disposal area along existing road nets, on a line perpendicular to predicted wind direction and at distances from 380-5500 meters from the burn site. The samplers on Stark Road were located at intervals of 0.3 mile and those on Goodyear Road at 0.5 mile intervals. They operated for approximately five hours during and after the burn, and were turned on for 2-4 hours on days subsequent to the burn.

Three Gelman samplers were located in the canyon itself about 30 feet from the north edge of one of the disposal trenches.

Soil sampling and fallout boards were also used. However, these samples have not yet been completely analyzed by the Laboratory and the results are not yet available.

Meteorological conditions for the test had been previously specified in the protocol. The assumption had been made that the test would not proceed unless the following conditions prevailed: Wind from SE, S, or SW Quadrants, wind speed above 10 mph, with Lapse conditions prevailing. These conditions were met during the test.

Both permanent and mobile meteorological stations were used during the test. Meteorological data was recorded at the following five locations: (See view graph #5)

a. Profile mast at the intersection of November and Stark Roads measuring wind speed and wind direction at 2 meter and 16 meter heights, and temperature gradient data.

b. Station #81 at the intersection of Lima Road and West Downwind Road measuring wind speed and wind direction at a height of 8 meters.

c. The C.P. at the west end of X-Ray Road measuring wind speed and wind direction at 2 meters.

d. Downwind #1-Northeast of the C.P. measuring wind speed and wind direction at 2 meters, and

e. Downwind #2 located approximately 6 miles northeast of the burn pit, measuring wind speed and wind direction at 2 and 16 meters. In addition, Pibal data (or winds aloft) were recorded at Station #81, Downwind #1 and Downwind #2.

During the test there was no cloud cover, temperature of the ground was 91.0 degrees, the relative humidity was 12 per cent, and temperature gradient or Δt (from a height of 2 meters to 16 meters) varied during

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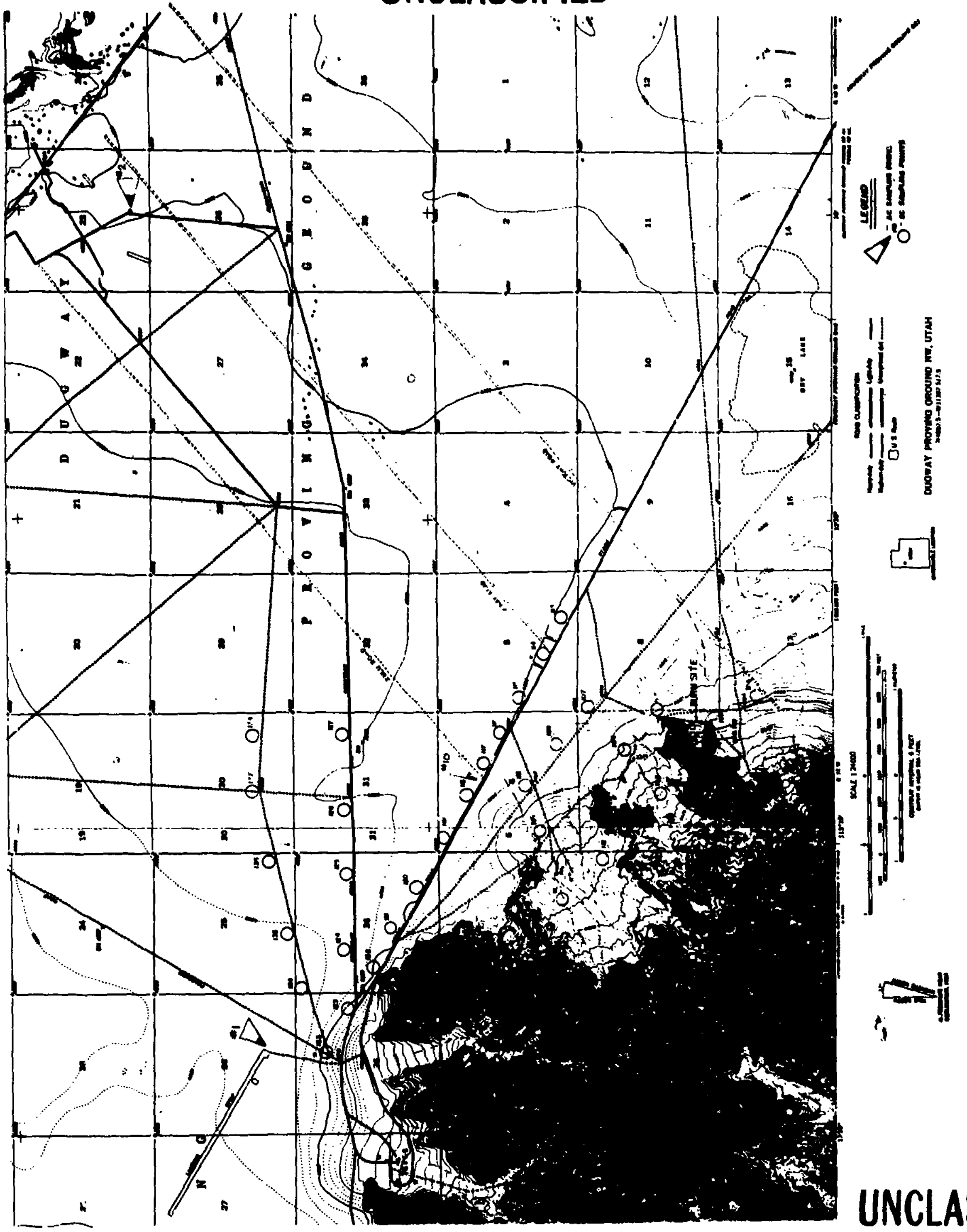

VIEW GRAPH NO. 4

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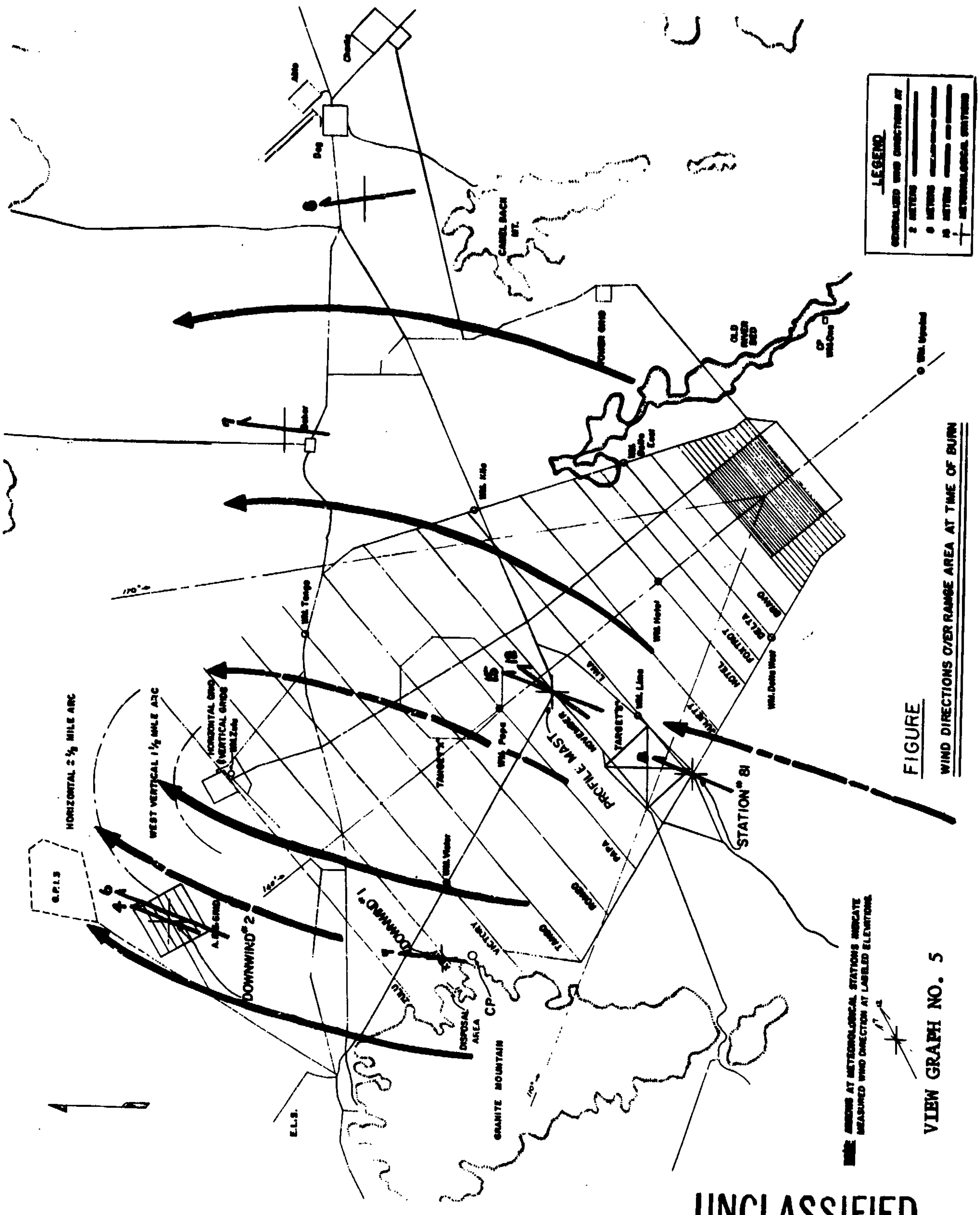

FIGURE

WIND DIRECTIONS OVER RANGE AREA AT TIME OF BURN

VIEW GRAPH NO. 5

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the burn period in a range from -0.2 to -3.9 degrees Fahrenheit. Fifteen minute averages of wind speed for all stations at all heights indicate variation from slightly under to slightly over 10 miles per hour. In general, winds were from the south-southwest. The stations closest to the mountain reflect a more southerly flow, and even a southeasterly flow after the first 90 minutes. Canyon winds were variable but primarily from the southeast, carrying the smoke over the canyon wall to the northwest.

Winds aloft were measured every hour at altitudes of 125 to 2290 feet from each of three stations. They were remarkably constant in direction, from the southwest and varied from an average of 10 mph at ignition, dropping to approximately 8 mph one hour after ignition, and rising again to approximately 20 mph by two hours after ignition.

The meteorological data plus visual observation and photographs were such to indicate that the samplers had been properly located.

At 1155, 9 July 1965, the beryllium waste was ignited by a group from the Explosive Ordnance Detachment located at Dugway. Five hundred gallons of fuel oil were poured over the barrels and ignited electrically using thermite grenades. At this time, I would like to quickly show a sequence of 35mm slides of the burn itself. I believe it will visibly demonstrate the dispersion that was obtained during the burn.

The fire in the trench had nearly burned itself out after the first 30 minutes, but smoke was still emitted for the following 90 minutes. At this time there were still visible emissions from the pit, although nothing like that seen during the earlier period.

After ignition, grass and sagebrush in vicinity of the pits caught on fire, and much of the smoke after the first two hours was due to this source.

What then are the results of this monitoring effort? First, a positive background sample was found in only one of the 56 pre-burn samples, and this was right at the detectable limit. This sample had been permitted to run for 56 hours rather than 24 hours. The indicated concentration was 10^{-4} micrograms per cubic meter or 1/100th of the 10^{-2} ug/m^3 permissible monthly average concentration in community air.

The next slide (see view graph #6) indicates the pattern of dispersion of beryllium to the range area, the lines representing contours of equal concentration. These samples in general represent four hours of sampling time beginning with ignition.

First, let us note the concentrations in the canyon itself. These are two hour samples. Concentrations of beryllium here are 202 ug/m^3, 145 ug/m^3, and 5.3 ug/m^3 respectively. The highest result is from the

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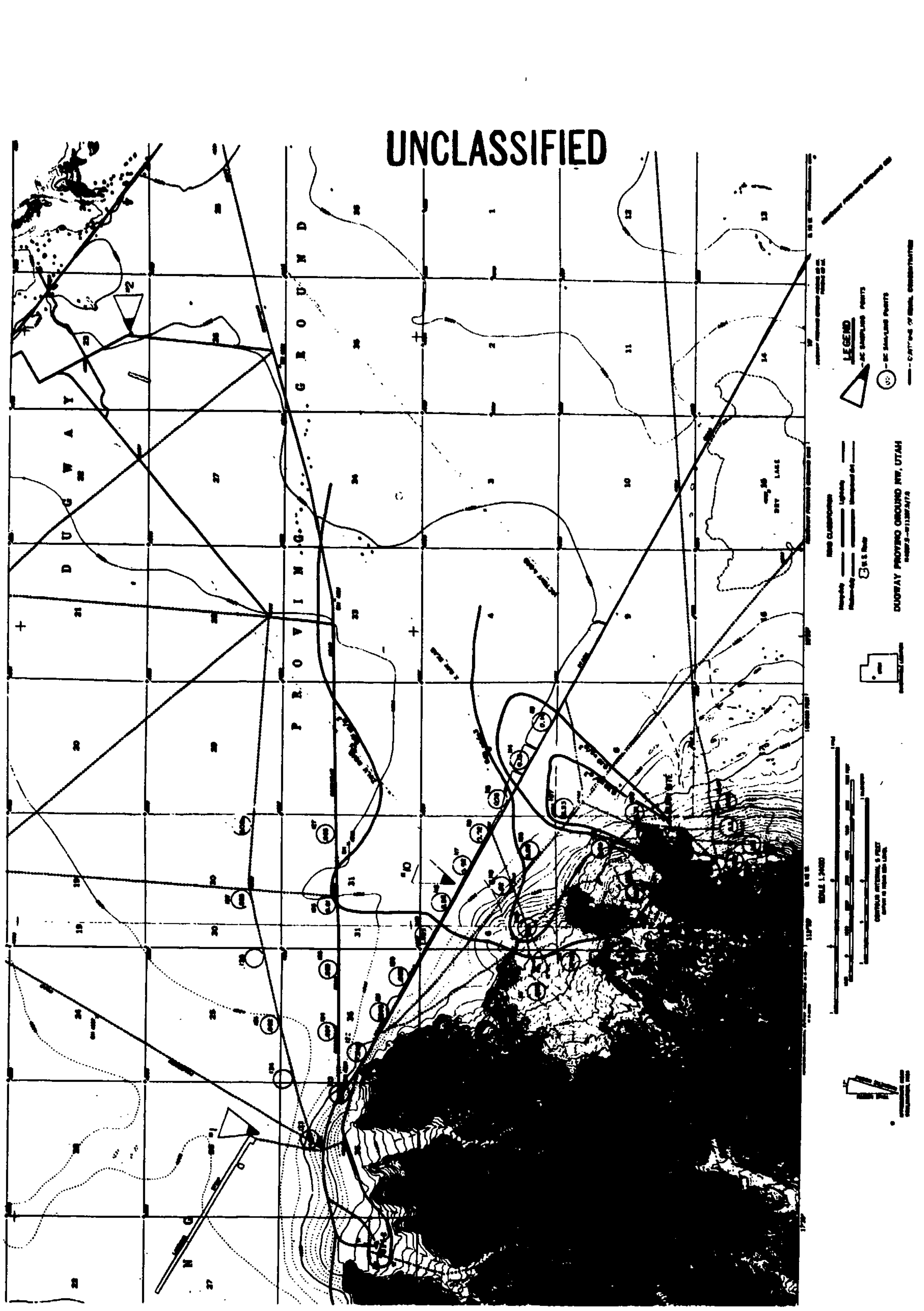

VIEW GRAPH NO. 6

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west end of the pit, and the lowest from the east end of the pit, reflecting wind direction in the canyon. At the end of two hours, we replaced these three samplers with two others. The reduced concentration during this second two-hour period were 4.0 ug/m^3 and 0.72 ug/m^3; again the higher concentration being on the west end. Inasmuch as the concentrations are so high during the first several hours, i.e., averaging more than 100 ug/m^3, anyone entering the canyon during this period should definitely wear a supplied-air respirator.

Now, note the lower concentrations outside the canyon. The highest value is .33 ug/m^3, or about 1/6 the permissible eight-hour average industrial exposure of 2/0 ug/m^3.

The contours represent 0.3, 0.1, 0.05 and 0.01 ug/m^3 concentrations respectively. The 0.05 line is significant because it represents the 60 day maximum permissible average community limit. The 0.01 line, of course, is the permissible 30 day average level.

For those of you interested in distances here, it is approximately 2000 meters from the canyon to the nearest point on Stark Road. The General Metal Works sampler located at sampling point #2 in the direct path of the cloud at a distance of about 8 kilometers indicated a concentration of 4×10^{-4} ug/m^3 or approximately 1/25th of the permissible community air level.

Off the range, in the surrounding communities, there were just three positive samples. At Delle, Callao, and at Dog area. All are just above detectable concentrations (0.0001 ug/m^3) and over one order of magnitude below permissible average monthly community levels.

During the days following the burn, sampling was continued. The trenches in the canyon were still open over the weekend. No emissions were visible from the trenches, but it was interesting to note that a smouldering tree burst into flame during one sampling run. During this two-day period, small concentrations were found on 10 of the high-volume samplers located in the vicinity of the canyon on the range. However, only one of these samples was at the maximum level recommended for community air; all the rest were below this level. This does indicate that there are small quantities of beryllium in the air after open trench burning, either as a result of fall-out, because of re-entrainment, or a continuing emission from the trench (either burning or ash being blown out of the trench).

On Monday, three days after ignition, covering over of the trenches with earth by use of a bulldozer began. This operation took several hours on each of two consecutive days. The operators wore full protective clothing, including a gas mask. Each man wore a lapel sampler while in the canyon. Additionally, a battery-operated staplex sampler was mounted on the dozer, and two Gelman samplers were operated

on sampling stands in the canyon. During this very dusty operation, the operator is exposed to beryllium concentrations of approximately 2-3 micrograms/m^3, or roughly to concentrations in the range of the permissible average industrial eight-hour level.

During the study, sampling was accomplished in the burn canyon, some 30 feet downwind from the trenches on six consecutive days, beginning at the time of ignition of the waste material. The graph (see view graph #7) you are now viewing shows the variation in concentration with time over this six day period. Note that this is a semi-log plot. After two hours of burning, the concentration in the pit was below 2.0 ug/m^3 on one sampler and slightly above this on the other. The day after the burn, the concentrations were below 0.1 ug/m^3. On Sunday they were slightly higher, and rose again when bulldozing began on Monday. During the dozing operation they fell off as the trench was covered. On Tuesday concentrations rose again when the dozer moved into cover the second trench. On the day after the trenches were covered over, both samplers had dropped to approximately the permissible air level.

This last curve (see view graph #8) shows the results of the burn when plotted against results obtained previously by Capt. Owen Kittilstad in his work on beryllium dispersion at Edwards Rocket Propulsion Lab in California. The line represents the peak concentration at various distances downwind one would expect when firing rocket engines. The x's and squares represent the open trench burning of small quantities of missile propellant at Edwards. These circles represent our results at Dugway Proving Ground. They are approximately one order of magnitude below the concentrations found at Edwards, and I believe indicate the reducing effect of Granite Mountain (and the nature of the waste materials) upon dispersion.

What then can be said to summarize these findings?

(1) Meteorological conditions prescribed for the test were proper to insure adequate dispersion of the beryllium. The occurrence of these conditions were predicted correctly by personnel at Dugway.

(2) Concentrations outside the canyon were well below the 2.0 microgram per cubic meter maximum 8-hour average recommended for industrial workers. After the first two hours of the burn, the level inside the canyon approached this level.

(3) Concentrations beyond Goodyear Road were below the recommended permissible 30-day average community concentration.

(4) Covering of the burn trenches reduces the concentration of beryllium in the air to a quantity below that of the recommended average community levels.

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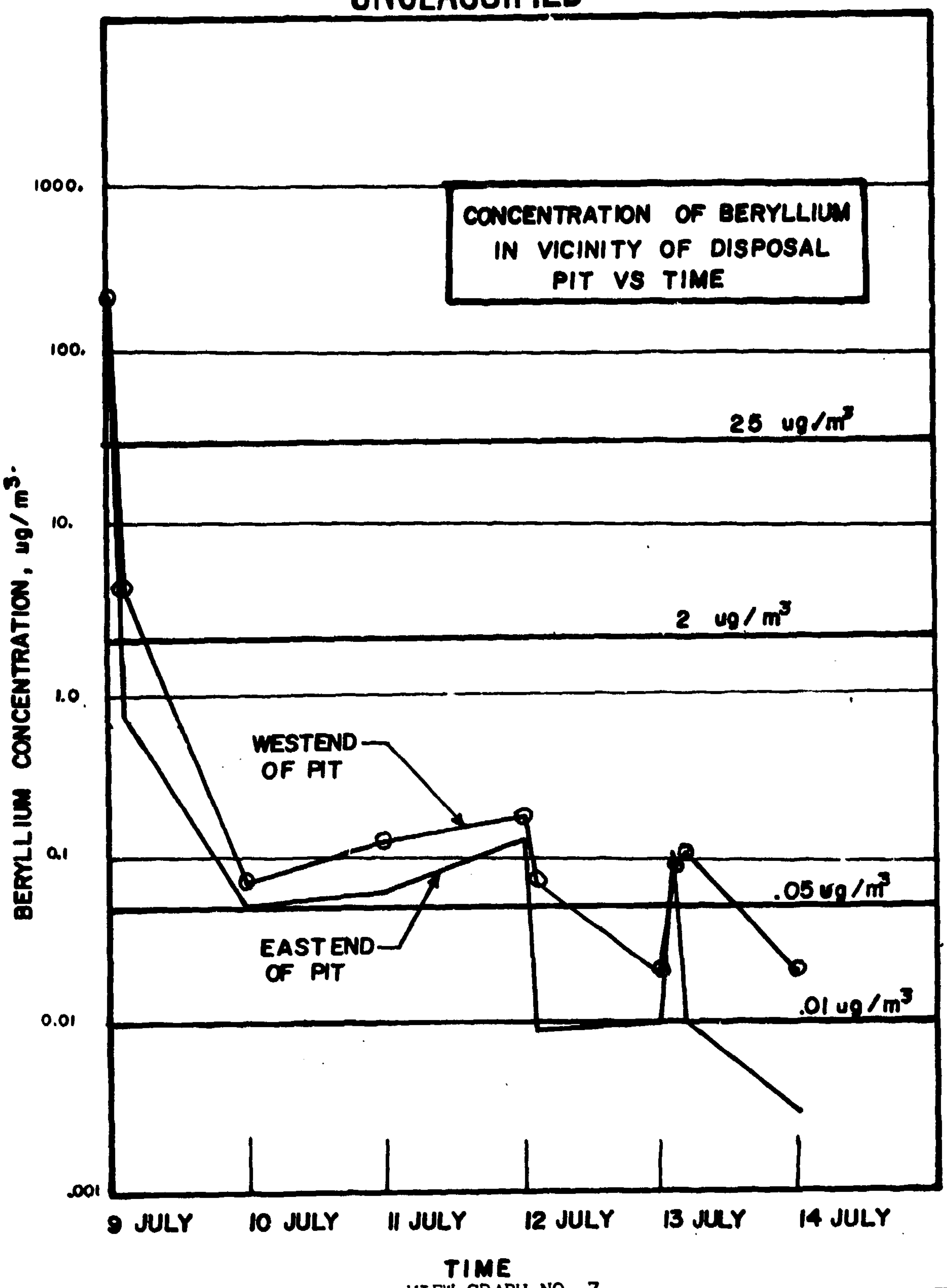

VIEW GRAPH NO. 7

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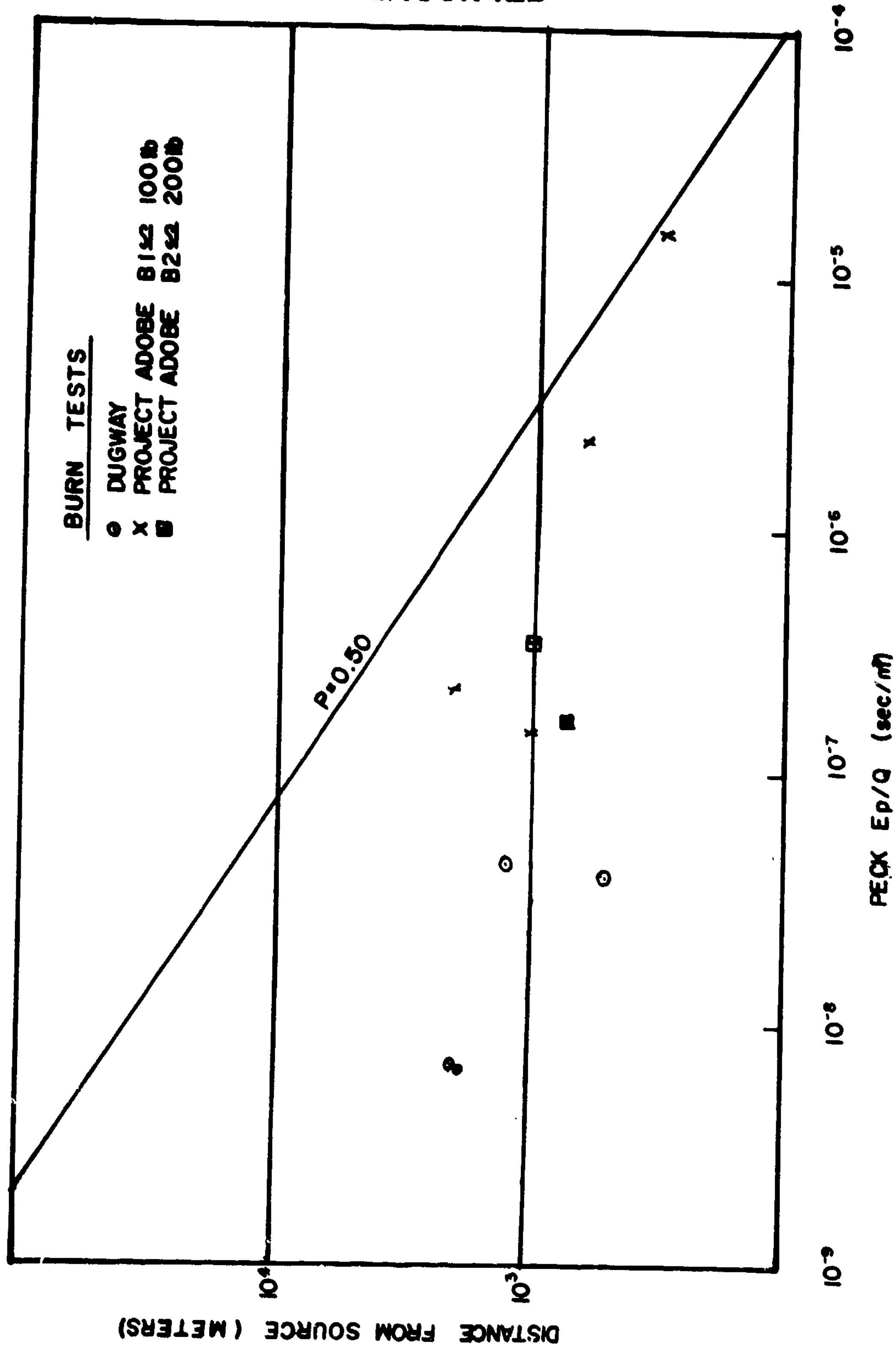
FIGURE: RESULTS OF OPEN PIT BURNING AT DUGWAY PROVING GROUND AND EDWARDS AIR FORCE BASE



VIEW GRAPH NO. 8

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(5) Finally, and most important of all, exposures to concentrations of beryllium by the civilian and military communities in western Utah was so low as to be minimal.

In conclusion, I would like to repeat the words used by the Chief, Division of Air Pollution USPHS, in approving the protocol for this test:

> "In our opinion, the interagency cooperation demonstrated in this plan for control of a potentially serious Federal air pollution problem is in complete harmony with the intent of Congress expressed in the Clean Air Act of 1963."

We hope that it was, and again want to thank all the members of the interagency team who participated in this test.

USAF - INDUSTRY EXPERIENCE; LOS ANGELES AREA

Maj. L. R. Channell, USAF
Space Systems Division
Los Angeles Air Force Station

In recent months, the Space Systems Division of the Air Force Systems Command has become involved in approval actions for siting toxic rocket motor test firing facilities. Ordinarily, Air Force contracts which would include the requirement for such facilities would come under the jurisdiction of the Air Force Rocket Propulsion Laboratory at Edwards AFB, Calif. which would establish facility siting criteria and perform siting evaluation. However, in the instances referred to above, the contractors were working under a NASA contract and the facilities were located at Air Force Plants under the jurisdiction of the Space Systems Division. Therefore, we were placed in the position of evaluating and recommending approval or disapproval for the facility sites.

I shall present here details concerning the negotiations involving two such siting actions for the storage of FLOX (Fluorine-oxygen) and for FLOX rocket motor test firing facilities.

Contractor number 1 desired approval for the siting of facilities for storing 1000 pounds of liquid fluorine and for test firing of motors utilizing 3300 pounds of FLOX containing 30% fluorine. The proposed facility is located in hilly terrain and the nearest off site housing is a farm house located 1.6 miles from the site. The restriction of the amount of fluorine to 1000 pounds is based on:

a. Total Integrated Dose (TID) from toxic cloud of 10 ppm-min fluorine (1 ppm for 10 min).

b. The utilization of the Sutton Instantaneous Point Source (IPS) for the TID at 1.6 miles under conditions of neutral thermal stability, wind speed of 5 knots and an effective chimney height (stabilized cloud height) of 200', gives a permissible source strength of 965 lbs.

c. No activity would be permitted; when wind speed is less than 5 knots; when wind direction is from 070° - 290°; during the time span of 30 minutes before darkness through the night; or during periods of heavy cloud cover.

Following a review by the SSD Surgeon's Office of the contractor's proposed facility and operating procedures (which included the aforementioned criteria) the following recommendations and comments were made to the contractor:

a. The contractor should establish on and off site (plant environmental (atmospheric) sampling stations which would be operated during potential toxic cloud passage and correlate the results obtained with that predicted.

b. The possibility or probability of fluorine storage tank rupture during inversion conditions should be investigated.

c. Obtain meteorological data such as surface temperature, ΔT (temperature variation with height), humidity and wind variation. Meteorological instrumentation for wind variation determination should have a more rapid response than the Aerovane. An instrument tower at the site should be used for making measurements.

d. The total integrated dose figure of 10 ppm-min fluorine used is considered reasonable although conservative. This judgement is based on the following Emergency Exposure Limits (EEL), formerly Emergency Tolerance Limits (ETL), promulgated by the National Research Council (NRC), National Academy of Sciences (NAS), Advisory Center on Toxicology.

NRC ETL for Fluorine (9 September 1963)

5 min	*2 ppm	10 ppm-min
15 min	1.5 ppm	23 ppm-min
30 min	1.0 ppm	30 ppm-min
60 min	0.5 ppm	30 ppm-min

*If for repeated exposures the concentration should not exceed 0.5 ppm (the TLV is 0.1 ppm).

NRC EEL (ETL) for Fluorine (1964 Revision)

5 min	5 ppm	25 ppm-min
15 min	3 ppm	45 ppm-min
30 min	2 ppm	60 ppm-min
60 min	1 ppm	60 ppm-min

NOTE: The NRC-NAS Advisory Center on Toxicology no longer puts out an EEL for 5 and 15 minutes exposure but has substituted, therefore, a 10 minute EEL. Thus only EEL's for 10, 30, and 60 minutes will be promulgated by this body in the future.

The contractor rebutted the recommendations as follows:

a. The use of on and off site samplers are not feasible due to:

(1) The topography of the site. (The site is in hilly terrain and the elevation in respect to off site occupied areas is around 700 feet higher. The mechanical mixing caused by the hills and the difference in elevations would operate to increase the cloud dilution rate and to extend the distance at which the diluted cloud would touch the ground.)

(2) The establishment of off site sampling stations in occupied areas would be likely to cause unwarranted concern among the populace.

(3) The conservative approach utilized in estimating downwind diffusion of the exhaust cloud plus operational restrictions would preclude the likelihood of exceeding the TID in uncontrolled occupied areas.

b. Fluorine storage tank rupture during an inversion situation is considered to be an unlikely event.

(1) No such incidents have been recorded.

(2) Work involving fluorine is permitted only when favorable meteorological conditions exist.

(3) Even if a large spill or tank rupture should occur during an inversion the vapor cloud would be trapped in the inversion layer and remain a considerable distance above the ground. Thus no harmful effects would be encountered at ground level.

c. The construction of a meteorological tower at the site is not considered necessary due to:

(1) Measurements taken at and on the tower would not be representative due to difference in elevation of off site areas and could not be utilized for off site diffusion predictions.

(2) The technique currently in use which utilizes on site wind and temperature information correlated with off site meteorological data has proven to be accurate.

The aforementioned requirements and comments were reviewed by the USAF Surgeon General's Office and the siting was approved in accordance with paragraphs 4-6b, AFM 161-2 and 4e, AFR 161-18A subject to the following requirements:

a. Limited air sampling be accomplished.

b. Validation of diffusion equations and sampling techniques to be reviewed, evaluated and approved by the SSD Surgeon.

c. A single, one-time, FLOX motor firing without atmospheric sampling is authorized if approved by the local air pollution authorities and witnessed by the SSD Surgeon or his representative.

In accordance with the siting approval by Hq USAF, the SSD Surgeon imposed these requirements:

a. No off site atmospheric sampling would be necessary.

b. A minimum of ten (10) on site samplers would be operated before, during, and after each static test firing (the location of sampling points are shown in Figure 1).

(1) Samplers would be Greenberg-Smith impingers operated at a sampling rate of 1 cfm and utilizing 0.1 normal NaOH as the sampling medium.

(2) Samplers would cover a 60 degree arc (30 degrees on each side of the mean wind direction).

(3) Samplers would be placed into operation 15 minutes prior to test firing and continue until 20 minutes after test firing is completed.

(4) The sodium-alizarin sulfonate method would be utilized to analyze samples. This method has a detection sensitivity under these conditions of 0.1 ppm fluoride.

c. Sample for ozone.

d. Forward sampling results to SSD as soon as possible.

e. Check local and vicinity air pollution index prior to firing to insure no air pollution alert is in effect or that air pollutants are approaching acceptable limits.

f. Advise local public health and air pollution control authorities of program and keep them advised concerning program progress.

Some results of the sampling program are shown in Figures 2 through 10. These results are given in ppm of hydrogen fluoride. The Total Integrated Dose (TID) at the various sampling points may be obtained by multiplying the ppm figure by the sampling time. As you have noticed, positive results were obtained from the first three firings - Figures 2, 3, and 4 - and that in each event the TID of 10 ppm-min was exceeded at least at one sampling point. Following the motor test firing the liquid fluorine remaining in the tanks was flushed to the atmosphere. The cool fluorine (hydrogen fluoride) vapors tended to flow along the ground surface with comparatively limited vertical diffusion. Subsequent to test number 515-017 (Figure 4) this practice was no longer followed and the sampling results of subsequent test firings are essentially negative. Total oxidants were determined from a sample taken during tests 515-020, 021, 022 and 023 (Figures 7 through 10.) These concentrations are essentially background for the area in question.

Some comments should be injected here concerning the knowledge gained from results obtained from site boundary sampling such as we have here. A static motor test firing is considered an instantaneous point source which yields a puff of hot gasses. This hot puff or cloud will rise until

it reaches a stabilizing height. This height is then called the "effective stack height". While this analogy is over simplified, it serves the purpose for which intended here. From this stabilized height, the cloud is carried by the wind in a down-wind direction and diffuses in all directions as it is carried along. The area occupied by the cloud as it moves along may be said to resemble a cone parallel to the ground with its apex over the firing site at the effective stack height. Thus, it is evident that there is an area or distance from the firing site to a point where the expanding puff or cloud touches the ground in which no toxic cloud vapors are present. If one has his sampling stations in this "jumped-over" area the results will almost always be negative whereas if the sampling station was farther down-wind at a point after the edge of the puff reached the ground positive results would be obtained. Thus, sampling along a site perimeter does not necessarily tell one what passes across the fence, unless, of course, the sampling is done in the vertical plane. It is for this reason, we feel that atmospheric sampling at a site boundary is of dubious value, if any. We recommend the utilization of atmospheric monitoring, by means of judiciously located samplers, in occupied uncontrolled areas which may be exposed to the exhaust cloud. Such monitoring would be conducted in conjunction with the use of adequate diffusion prediction equations and a thorough knowledge of the area micrometeorology.

Let us go on to Contractor number 2. Here again, the contractor desired approval for the siting of FLOX facility, with the exception of this being an expansion of existing facilities. The initial approval request was dated 15 December 1964. The facilities included the installation of 100 gallon and 500 gallon liquid fluorine tanks with a maximum of 1260 pounds of liquid fluorine to be utilized at any one time.

The plant was visited on 5 February 1965 by the SSD Staff Bioenvironmental Engineer and by an SSD Meteorologist. As a result of this visit, information concerning the following subjects was requested from the contractor:

a. Resume of contractor experience with toxic propellants.

b. Medical Support Program.

c. Industrial Hygiene and Safety Support Program.

d. Exhaust products inventory.

e. Ecological and environmental sampling of area.

f. Detailed F_2 and HF sampling techniques.

g. Meteorological controls for test firing.

h. Meteorological data available, kind, length of records, diffusion prediction equations, parameters used, determination of prevailing winds.

i. Evaporation rate of liquid fluorine.

j. Data, specifications, and experience on scrubber.

k. Frequency and duration of test firings.

l. Maps of immediate and surrounding area.

m. Toxic wastes disposal.

After some delay, the required information was provided and pertinent points are summarized as follows:

a. The diffusion prediction equations developed by Pasquill are used to determine down-wind hazard from toxic clouds.

b. Two and one-half years of diffusion climatology observations are on record and available.

c. Meteorological control exercised includes:

(1) Determination of lapse rate.

(2) Determination of wind velocity and direction.

(3) The allowable source strength is calculated using the above data in graphs based on Pasquill for the limiting distance to occupied areas and the limiting TLD.

d. The meteorological data available and the use thereof was considered satisfactory. However, it was felt that efforts to better define the area diffusion characteristics should continue.

e. The siting of the FLOX facilities was approved subject to the following:

(1) A comprehensive atmospheric sampling program at site boundary be instituted to confirm adequacy of meteorological control measures.

(2) Sampling results and instrumentation used shall be recorded and maintained for reference.

(3) Install at least 10 sampling locations along down-wind plant perimeter with 10° spacing.

(4) Samples shall be taken for each firing.

(5) Sample analysis for fluorides shall be in accordance with procedure given on page 335f, "The Chemistry of Industrial Toxicology, 2d ed, H. B. Elkins.

(6) The lime paper sampling technique is satisfactory for qualitative sampling but is unproven for quantitative sampling.

(7) Exposure criteria shall be:

Emergency Exposure Limits (EEL)

Time (min)	Concentration (ppm) HF	F_2
5	30	5
15	20	3
30	10	2
60	8	1

Threshold Limit Values (TLV)

HF	3 ppm/8 hour
F_2	0.5 ppm/8 hour

Non-Occupational TLV

	Peak	Average
HF	5 ppm/10 min	0.03 ppm/14 days
F_2	0.5 ppm/10 min	0.01 ppm/14 days

NOTE: These are not the EEL or TLV's as currently recommended by the NRC-NAS Advisory Center on Toxicology, therefore, they must be considered as only being applicable to the site and conditions of this particular contractor.

(8) Normal fluoride background of soil and water shall be determined and recorded. Build-up as a result of fluorine operations shall be ascertained and recorded.

Summarizing, it can be noted that considerable time was lost in completing the approval action due to, among other items, indecision concerning minimum information required to be furnished by the contractor, differences of opinion concerning atmospheric sampling requirements, inadequate definition of the micrometeorological regime for the site and immediate area, and perhaps inconsistency in exposure criteria to the toxic fumes involved. In the cited instances, one contractor used a diffusion prediction equation from Sutton, while the other used the method devised by Pasquill. We do not insist on the utilization of any particular method as long as the contractor is able to properly defend the one he uses and is able to verify the results he obtains from its use.

A brief outline of the information we require for adequate siting evaluation and which we expect the contractor to furnish is as follows:

a. General.

(1) Contractor experience.

(2) Qualifications of key personnel.

(3) Facility layout and site plans or map.

(4) Area maps (local).

b. Toxicity data and criteria (EEL's, TLV's).

c. Comprehensive Industrial Hygiene, Medical, and Disaster Control Programs.

d. Comprehensive meteorological data and meteorological control programs.

e. Operational plan and schedules.

As pointed out previously, although we do not insist on any particular diffusion prediction method, we do recommend the use of the following equations:

a. Ground level continuous point source:

$$\frac{C_p}{Q} = 0.000175 \; x^{-1.95} \; (\Delta T + 10)^{4.92}$$

where:

C_p is the peak concentration in gms/cubic meter at a height of approximately 5 feet above the ground at a given downwind travel distance, X in meters.

Q is the source strength in gms/sec.

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ΔT is the difference, in $^{\circ}F$, between the temperature at 54 feet and 6 feet above the ground.

(Reference AWS Technical Report 176, 10 Feb 1964.)

b. Instantaneous point source:

$$X = 0.284 \left(\frac{Ep}{Q}\right)^{-0.714}$$

where:

Ep = peak (centerline) integrated dose (exposure) in units (mg or ug) per cubic meter per time period (min or sec).

Q = Source strength in units (mg or ug).

$\frac{Ep}{Q}$ = peak exposure normalized for source strength in units of time per cubic meter.

X = downwind distance in meters.

NOTE: 9[illegible] percentile confidence level equation.

(Reference AFCRL Preliminary Report Project SAND STORM.)

c. Defining corridor width:

$W = 1.8R$

where:

W = width of 95% hazard corridor in degrees azimuth.

R = range of wind direction in degrees.

(Reference AWS TR 176.)

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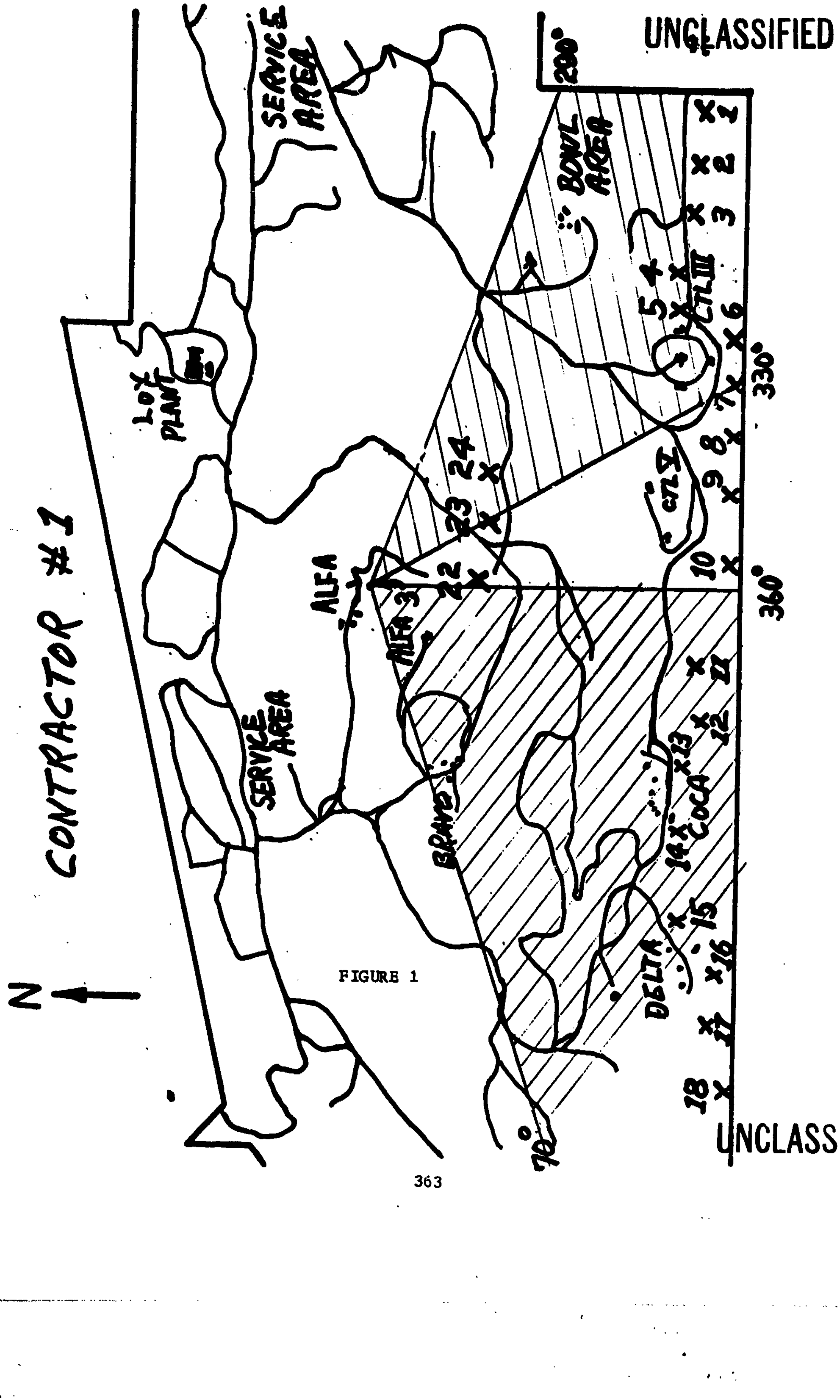

FIGURE 1

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Test No. 515-015

Date: 24 February 1965
Time: 4:36 P.M.
Duration: 15 seconds
Fluorine Used: 990 pounds

Average Wind Velocity: NW, 11 knots
Weather: Partly cloudy, visibility unlimited

Sampler Location	Duration of Sampling	PPM*
1	17 min	0.20
2	17 min	0.16
3	17 min	0.22
4	17 min	0.15
5	17 min	1.06
6	16 min	0.03
7	16 min	-
8	16 min	-
9	16 min	-
10	16 min	-

*Parts of hydrogen fluoride per million parts of air.

FIGURE 2

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Test No. 515-016

Date: 26 February 1965
Time: 5:27 P.M.
Duration: 15 seconds
Fluorine Used: 920 pounds

Average Wind Velocity: NW, 5 knots
Weather: High overcast, visibility unlimited

Sampler Location	Duration of Sampling	PPM*
1	30 min	0.22
2	30 min	0.21
3	30 min	0.37
4	30 min	0.24
5	30 min	0.21
6	30 min	0.61
7	30 min	0.46
8	30 min	0.52
9	30 min	0.42
10	30 min	0.25

*Parts of hydrogen fluoride per million parts of air.

FIGURE 3

Test No. 515-017

Date: 1 March 1965
Time: 5:34 P.M.
Duration: 3.4 seconds
Fluorine Used: 500 pounds

Average Wind Velocity: NE, 6 to 7 knots
Weather: Clear, visibility unlimited

Sampler Location	Duration of Sampling	PPM
9	17 min	0.47
10	17 min	0.36
11	25 min	0.35
12	28 min	0.33
13	30 min	0.28
14	32 min	0.23
15	35 min	0.23
16	36 min	0.26
17	36 min	0.25
18	41 min	0.22

FIGURE 4

Test No. 515-018

Date: 2 March 1965
Time: 4:33 P.M.
Duration: 1.5 seconds
(Transition - No Mainstage)
Fluorine Used: 170 pounds

Average Wind Velocity: NNE, 9 knots
Weather: Clear and sunny, visibility unlimited

Sampler Location	Duration of Sampling	PPM**
6	22 min	-
7	22 min	-
8	22 min	Trace**
9	22 min	-
10	22 min	-
11	20 min	Trace
12	16 min	-
13	19 min	-
14	26 min	-
15	58 min	-

**Trace-Less than 0.05 parts of hydrogen fluoride per million parts of air.

FIGURE 5

Test No. 515-019

Date: 8 March 1965
Time: 4:27 P.M.
Duration: 15 seconds
Fluorine Used: 900 pounds

Average Wind Velocity: NW, 10 knots
Weather: Sunny, partly cloudy, visibility unlimited

Sampler Location	Duration of Sampling	PPM
1	16 min	-
2	16 min	Trace
3	16 min	-
4	16 min	-
5	16 min	-
6	22 min	-
7	22 min	Trace
8	22 min	-
9	22 min	-
10	22 min	-

FIGURE 6

Test No. 515-020

Date: 12 March 1965
Time: 2:07 P.M.
Duration: 15 seconds
Fluorine Used: 1,000 pounds

Average Wind Velocity: W 9 to 11 knots
Weather: Partly cloudy, visibility unlimited

Sampler Location	Duration of Sampling	PPM
1	10 min	-
2	10 min	-
3	10 min	-
4	10 min	-
5	10 min	-
3 (total oxidants)	10 min	0.01 mg/m^3

FIGURE 7

Test No. 515-021

Date: 15 March 1965
Time: 2:29 P.M.
Duration: 17.3 seconds
Fluorine Used: 1,000 pounds

Average Wind Velocity: NW, 6 knots
Weather: Cloudy, rain

Sampler Location	Duration of Sampling	PPM
1	21 min	-
2	21 min	-
3	21 min	-
4	21 min	-
5	21 min	-
6	31 min	-
7	31 min	-
8	31 min	-
9	31 min	-
10	31 min	-
19	37 min	0.08
20	27 min	-
3 (oxidants)	21 min	0.076mg/m^3

FIGURE 8

Test No. 515-022

Date: 16 March 1965
Time: 4:24 P.M.
Duration: 16.5 seconds
Fluorine Used: 930 pounds

Average Wind Velocity: NW, 8 knots
Weather: Cloudy

Sampler Location	Duration of Sampling	PPM
1	26 min	-
2	26 min	-
3	26 min	-
4	26 min	-
5	26 min	-
6	30 min	-
7	30 min	-
8	30 min	-
9	30 min	-
10	30 min	-
19	28 min	-
20	28 min	-
21	71 min	-
3 (oxidants)	26 min	0.8
		$0.037 mg/m^3$

FIGURE 9

Test No. 515-023	Date: 16 March 1965
	Time: 4:24 P.M.
	Duration: 16.5 seconds
	Fluorine Used: 930 pounds
	Temperature: 45°F
	Relative Humidity: 85%

Average Wind Velocity: NW, 8 knots
Weather: Cloudy

Sampler Location	PPM
1	-
2	-
3	-
4	-
5	-
6	-
7	-
8	-
9	-
10	-
19	-
20	-
3 (total oxidants)	0.056mg/m^3 0.028ppm O_3

FIGURE 10

AFETR ENVIRONMENTAL CONTROL PROGRAM *

Colonel William H. Lee, BSC, USAF
Hq AFETR (ETXH)
Patrick AFB, Florida

Thank you Lt Colonel Peterson. I wish to thank you and the Armed Services Explosives Safety Board for the opportunity to present this information.

The purpose of this paper is to discuss our program for environmental control on the Air Force Eastern Test Range (AFETR). This includes the basic criteria for the on-site Cape Kennedy Air Force Station (CKAFS) study program conducted for the Air Force by Pan American World Airways (PAA), the joint U. S. Air Force/U. S. Public Health Service (USPHS) Off-Site Environmental Study, and our program on air pollution in assessing environmental impact within launch areas.

The intent of the over-all program is to establish naturally occurring concentrations of residual nuclide activity and certain elements/compounds that are in use or programmed by AFETR operations which may have harmful or toxic significance. Such information would enable legal assessment of any area contamination that could be

attributed to the transport of bulk chemical or nuclear assembly, or to an off-site impact of a booster assembly or flight test, or to assess air pollution due to booster exhaust.

The concept of the off-site study was established by a joint agreement of the Division of Radiological Health, USPHS, and the AFETR, with the management and resources of the Deputy for Bio-astronautics, AFETR. In the off-site areas, sampling sites were placed into three categories located within each ten-mile sampling radius beginning at CKAFS and extending westward, northward, and southward for 50 miles. The three sampling site categories were referred to as (1) hard-site, (2) soft-site, and (3) random-site collection stations. (There should be a minimum of ten hard-sites per ten-mile sampling radius.)

The designated difference between the three sampling sites is as follows:

Hard-Site Area. That area which provides easy accessibility, and which provides most, if not all, the standard items to be sampled found in the "Specimen Log." This area should remain constant, as to location, in order that sampling operations can continue on a permanent, periodic basis.

Soft-Site Area. That area in the immediate vicinity of a hard-site

area which supplements it. This area should provide those specimens otherwise unattainable from a hard-site area on a periodic basis.

Random-Site Area. That area non-adjacent to a hard-site or a soft-site area, which should be sampled at the discretion of the technician. This is an area which might produce unique and significant types of specimens, which may not have been previously considered or studied as biological indicators.

Frequency of collection of samples selected was controlled by many factors such as seasonal growth, area predomination, availability, accessibility, and the degree to which the sample is utilized in the human diet. Such stable samples as potable and unpotable water, certain vegetation, soil, silt, air, milk, and meat can be collected continually and periodically throughout the calendar year.

Hard-site areas were established on the basis of continuous sampling; i.e., one specific sample per month. Soft-site areas should be selected for seasonal collection during growth or developmental stages and may be more advantageous for the measurement and detection of the nuclear and toxic agents with which we are concerned. Random sites are to be used for collection for the interest of investigator and the advancement of knowledge in this field.

For the pilot study, it was established that ten allied samples

from each of the five ten-mile radial arcs shall be sampled once each month. Furthermore, a linear type collection should be established, which will include as nearly as is possible identical or familial specimens from each arc from CKAFS and J. F. Kennedy Space Center. (See figure 1 for the five sampling areas.)

This off-site program was initiated 1 January 1965 and to date 316 samples, with a total of 2124 analyses, were accomplished.

During 1-3 December 1964, a symposium was held at Patrick AFB with over 100 representatives of universities and federal, state, and local public health groups. The entire program was devoted to the cause and effect of this off-site study and its intent and program were made clear to all attendees.

In conjunction with the off-site study, we have a CKAFS on-site study which is being conducted by PAA Environmental Health Laboratory. The location of the sampling points are indicated in figure 2. It can be seen that the 23 sampling points are spread throughout the Cape.

The type of analyses performed is shown in figure 3. The analyses varied from gross alpha and beta to nitrite, nitrate, fluoride, UDMH, boron, beryllium, and hydrocarbons. The samples varied from water, both fresh and salt, to palmetto, fish, crab, and oyster. As a result of these studies, a residual level of toxic chemicals has been determined.

Besides the environmental studies, there is a program to study the pollution potential of the various missile systems. As an example of this study, I will show the results of a study conducted on the first Titan IIIC launch in June 1965.

This study was initiated to observe cloud behavior and to obtain the downwind concentrations of exhaust products from the Titan IIIC launch. The cloud behavior was recorded by three cameras located as shown in figure 4. We will now show the edited film from these cameras.

The downwind concentrations from the cloud were obtained by placing samplers as indicated in figure 5. The weather conditions prevalent at the time of launch are shown in figure 6 and the actual results are shown in figure 7. It can be seen that the concentrations of HCl are much lower than can be expected. The main exhaust product to cause concern is carbon monoxide, which was present in high concentrations. Due to weather conditions prevalent at the time, the exhaust cloud lifted and cleared the pad in a matter of minutes.

I hope that this talk has shown the many studies necessary to show that our environment is not being contaminated by the missile operations at CKAFS. The data obtained will also provide us with medico-legal information for protection against any future suits involving the government.

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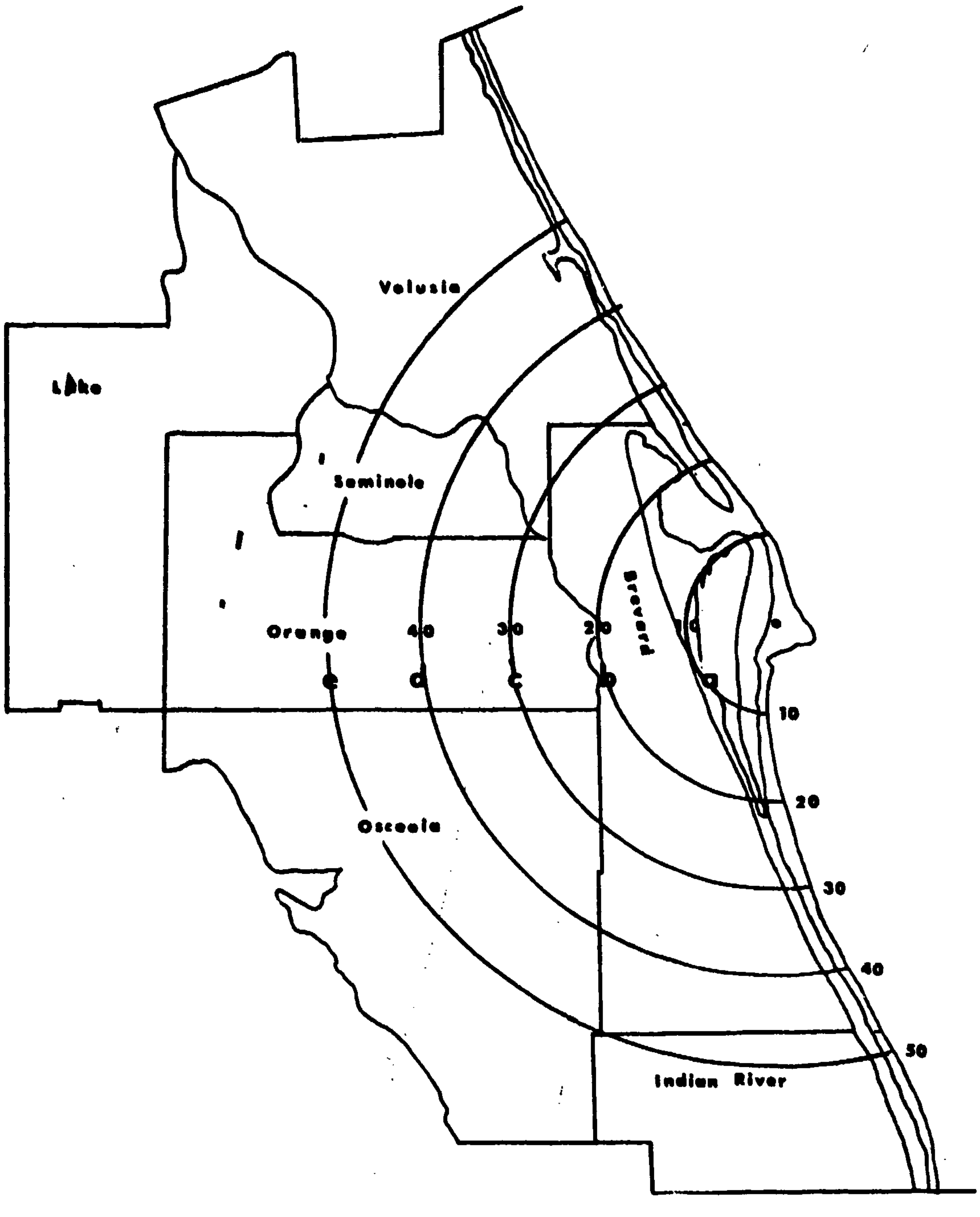
Figure 1



Scale in Miles

0 10 20 30 40 50

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ENVIRONMENTAL BACK GROUND STUDY SAMPLE COLLECTION SITES ON CKAFS AND MILA

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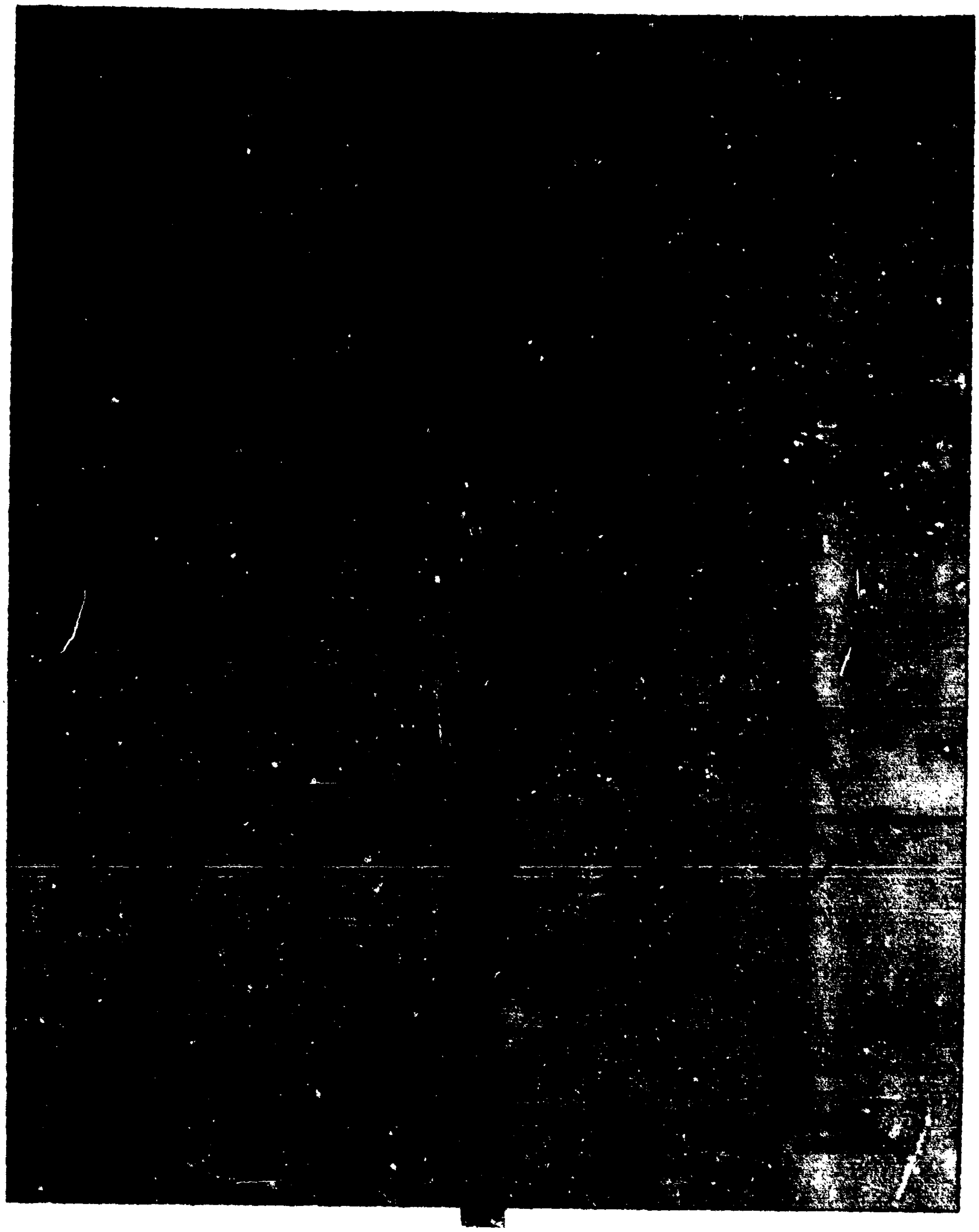

Figure 3 **UNCLASSIFIED**

TABLE II

ENVIRONMENTAL BACKGROUND STUDY

ANALYSIS CHART, 1964

LABORATORY	ANALYSIS	SAMPLE TYPE												
		W A T E R						VEG	SOIL	ZOOLOGIC				AIR
		Tidal	Silt	Potable	Raw	Well	Canal	Palmetto	Surface	Fish	Shrimp	Crab	Oyster	Filter
USPHS, ALABAMA	GROSS α & β	X	X							X	X	X	X	X
WRIGHT-PATTERSON AFB, OHIO	GROSS α & β	X	X	X	X	X	X	X	X	X	X	X	X	
PAA ENVIRONMENTAL HEALTH LABORATORY	GROSS α & β		X	X	X	X	X	X	X	X	X	X	X	X
	NITRITE			X			X							
	NITRATE			X			X							
	FLUORIDE			X			X	X	X					
	UDMH			X			X							
KELLY AFB, TEXAS	NITRITE			X			X							
	NITRATE			X			X							X
	FLUORIDE			X			X	X	X					
	BORON			X			X	X	X					
	BERYLLIUM							X	X					
	HYDROCARBONS			X			X							
	UDMH			X			X							
ETORL, PATRICK AFB	BERYLLIUM							X	X					X

Figure 3

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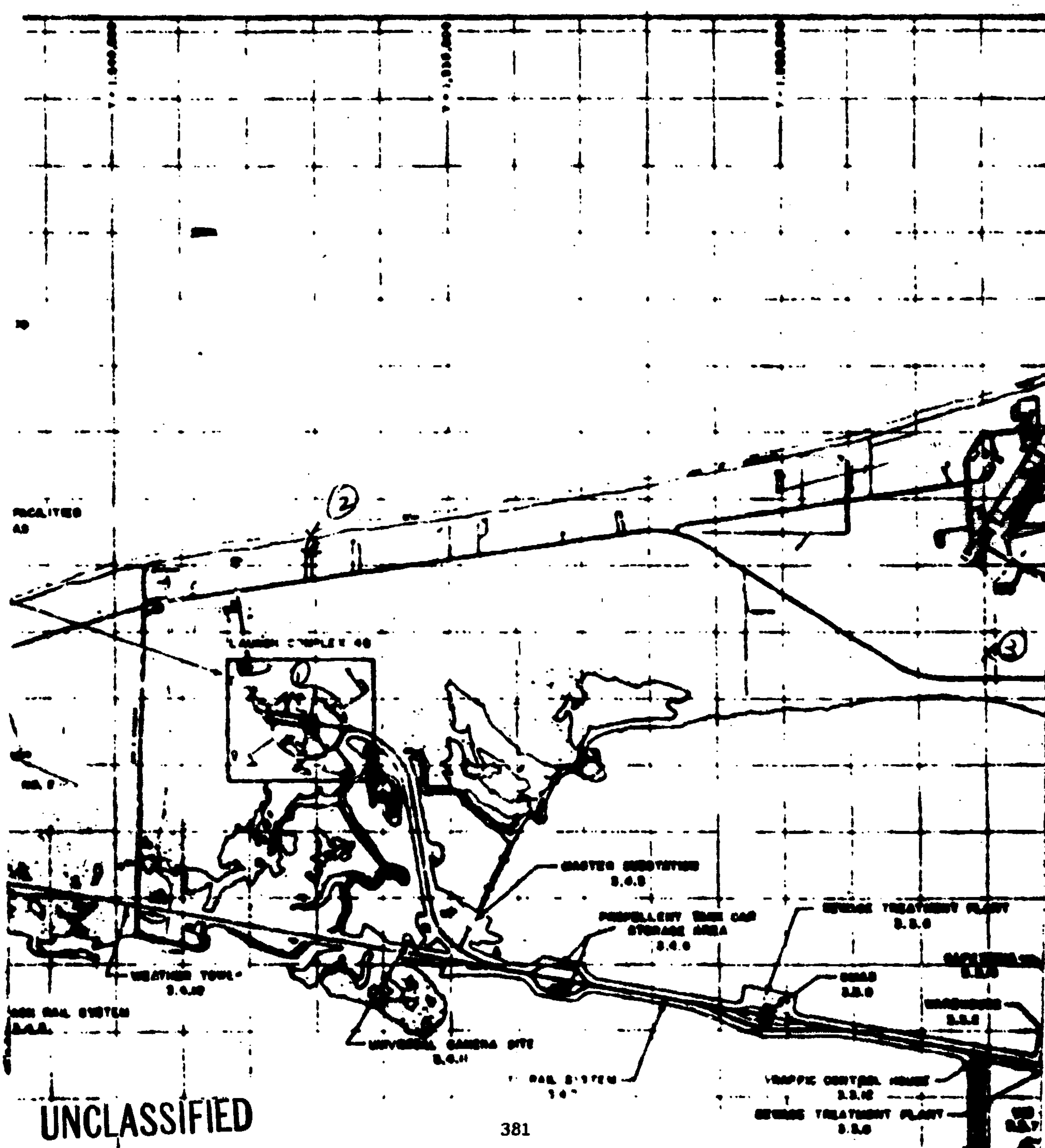
Figure 4

PAA INDUSTRIAL HYGIENE ENGINEERING

ATTACHMENT #5

CLOUD BEHAV AND DOWNWIND CONCENTRATIONS

MERA LOCATIONS



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PAA INDUSTRIAL HYGIENE ENGINEERING

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ATTACHMENT #1

CLOUD COMPOSITION AND PENETRATION TITAN IIIC SAMPLE LOCATIONS

Figure 5

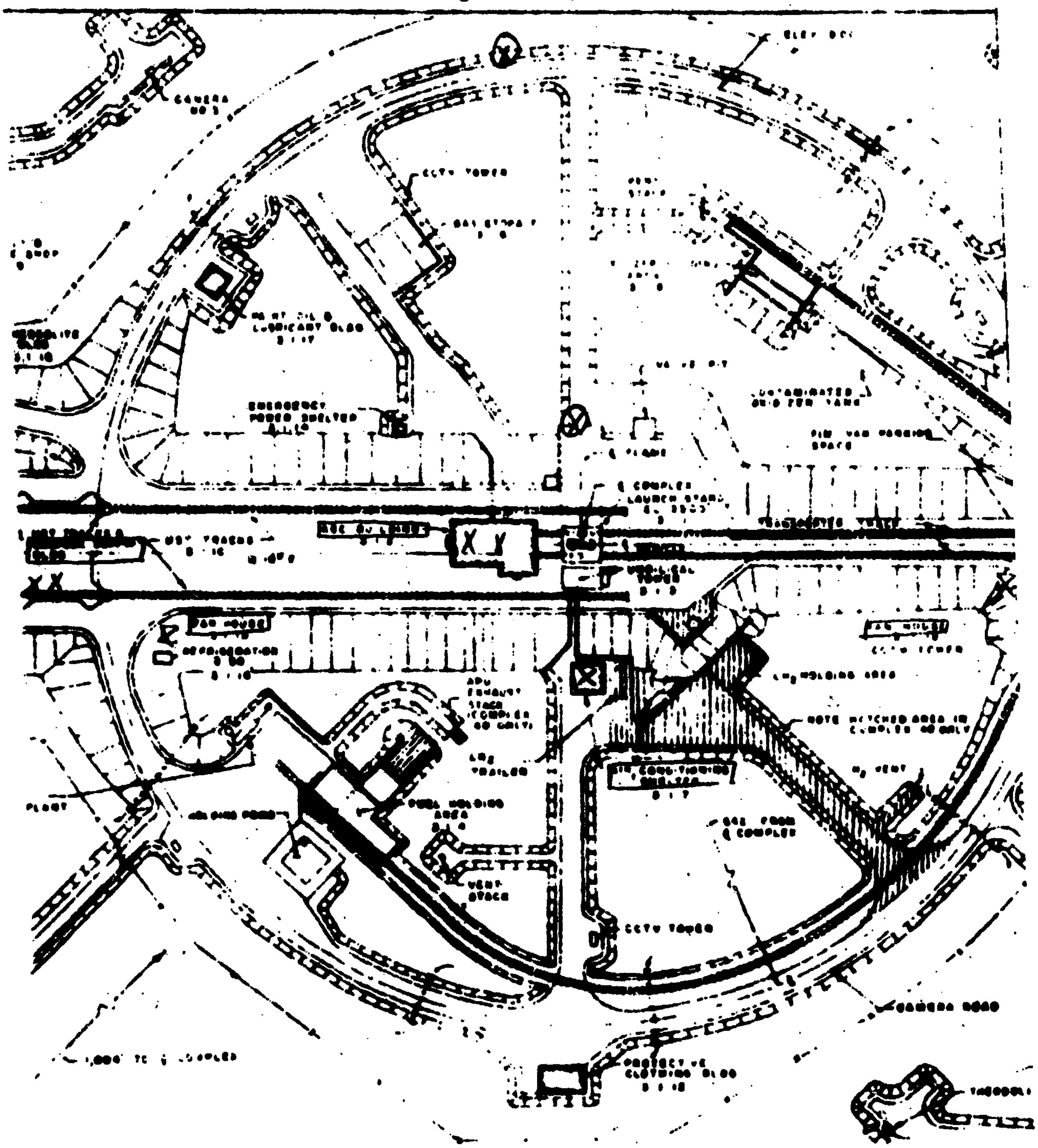

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Figure 6

PAA INDUSTRIAL HYGIENE ENGINEERING

ATTACHMENT #7

WEATHER CONDITIONS AT STATION 702 AT THE TIME OF LAUNCH (0900)

ALTITUDE (ft)	WIND°	SPEED (k)	σ	ΔT
12	205	1	10.4	
54	215	4		-3.7
162	190	5		-0.1
204	221	6		

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Figure 7

PAA INDUSTRIAL HYGIENE ENGINEERING

ATTACHMENT #2

CLOUD COMPOSITION AND PENETRATION - TITAN IIIC

NO.	LOCATION	PPM					%	
		HCL	NO_2	CO	CO_2	H_2	H_2O	N_2
1	Flame Bucket - lip	24[1]	17	14,500 (1.45%)	46,000 (4.6%)	565	4.3	70.5
2	Flame bucket -450'	28-40[2]	0	0	272	<5	4.0	74.5
3	AGE-Van level, S. end	17-26[3]	4.6		1880	< 5	2.8	76.2
4	AGE-lower level, rack room	0	-	-	-	-	-	-
5	CSB-Martin Prop. Shop	0	0		240	< 5	2.0	76.7
6	CSB-UTC Shop	0	-	-	-	-	-	-
7	Fan house-north	0	0		234	< 5	3.7	75.6
8	Fan house-south	0	-	-	-	-	-	-

1 - 40 sec. sample (time to clean complex)
2 - 30 - 40 sec. sample
3.- 40 - 60 sec. sample

MEMBRANE FILTER SAMPLE RESULTS

LOCATION	ALUMINUM Al_2O_3
AGE-lower level*	Less than 0.1%
Complex Support Bldg. UTC Shop	Less than 0.1%

* Filter contained in heavy deposit, possibly due to smoke from fire at base of umbilical tower.

Weiss, Rocketdyne: Most of my comments will be directed to Maj. Channell inasmuch as I don't think it need be kept a secret that contractor #1 was Rocketdyne - Santa Susana, in particular. We were the first of the contractors using fluorine to have this established liaison with SSD and at the same time with Col. Meyer's organization in Washington. Most of this will be in the form of a statement. First of all, I think that Maj. Channell as an individual was rather unfortunate in that he didn't participate in the early discussions relative to this problem and some of his talk reflected a lack of detailed background information. Without disparaging the talk too much, I think its fair for everybody who listens to the talk to understand that there are many more details of information that are usually covered relative to a particular site. And if there is one common denominator that should be brought out from all of this, it is that drawing of general meteorological criteria and drawing of general equations is usually an inadequacy in the total evaluation. One of the prime problems that usually develops is the over-generalization of meteorological aspects of the problem in particular and along with that as a corollary is a lack of detailed toxicological criteria to work with. I see Dr. Pete Ricca here, he might want to comment on this in a little more detail but relative to the particular talk there were some conclusions drawn - whether they be Maj. Channell's or the general SSD conclusions. One of the overshooting of the samplers for instance. There's a comment that's important now and that is that one of the original criteria drawn for using fluorine at this site is the effect of the particular contour of the terrain. Santa Susana is located on a knoll approximately 900 ft. above the generally populated terrain in the vicinity and it was felt that this would be one of the prime benefits to be derived from this location rather than a problem. We felt that the sampling was just a superficial appendage to the program. We felt that the prime benefit was the fact that the cloud would be considerably above the points of interest. I think that much more generally, what I would like to say to the group as a whole is that we can see that we are just at the beginning of touching the problem from the joint aspect. Those who are in the monitoring position and those contractors who are involved must obviously get together in much greater detail and we can see that in this aspect of the drawing of general conclusions before contacting the contractor and discussing as I think is one of the fallacies in the argument. Also, I notice that in the tables that were presented there was a glossing over of the fact that the original criteria were drawn conservatively based on fluorine whereas the concentrations that were shown were for HF which has different toxicological aspects and rather than going into the details, I took voluminous notes and I've decided now that I'd better not go into such detail. I think basically I would like to say that we have an indication here that we are all presented with a real problem based on legislative activity in the Congress, the will of the executives, and the fact that certain activities in the national interest will obviously take place. I feel and I'm sure that the bulk of you feel the same way - that much more activity in

terms of joint effort is needed. I don't think that any particular single activities should either be impugned or congratulated but rather form a base for what is obviously going to be a lot more joint effort in this area.

Channell: I was not attempting to impugn anyone. What I was attempting to do by my talk was to show the problems we had run into in this particular area. I will agree that I did make the assumptions that we were jumping over that particular sample. However, this is an assumption on my part and it's based somewhat upon the experiences from another contractor who has experience on the same thing. Whether or not there were concentrations further downwind from this particular site, no one can say. I can't say, and I don't believe that you folks can say either. In other words we are faced with a matter of opinion here I think. I prefer not to get into this aspect of it any further but I think that you folks did a fine job on what you were doing there and I think you did go conservative as I mentioned in my talk.

Weiss: I'd like to make one more statement. I think that the bulk of the problem as I see it is that even within the meteorological profession itself there is somewhat of a difference of opinion as to how to clearly define all of the parameters that go into evaluating this problem. I think its unfair for people to try to delineate with absolute certainty all of these parameters when I myself as an individual have engaged in lengthy conversations with fellow meteorologists and wind up more or less agreeing to forget our mutual differences of opinion. The only point I was really making is that the problem is very complex and I would like to discourage the attempts made at simplification.

Dr. Ricca, Kennedy SC: I have one comment and two questions. Regarding some comments Capt. Lawrence made on the place of the various Federal legislation in determining the activities of Federal agencies in controlling and policing their pollution - at what point do you in the Public Health Service consider in an aerospace R&D test program that the transition should be made from simplified off-side monitoring procedures to a more sophisticated program of refined techniques of ecological imbalances?

Lawrence: I'm afraid I can't answer that question on such short notice.

Ricca: I have one for Capt. Kittilstad. He commented on the possibility of Edwards Air Force Base developing a wind meteorological system. Are you in a position to comment on which mathematical model you plan to program with your computer?

Kittilstad: Of course as you know, you can put any model you want into one of these computers. I would expect at this time that the model that we are probably going to throw in as far as continuous point sources is the one that Maj. Channell had on the board - one of

the ones that came out of the "Ocean Breeze-Dry Gulch" - and the one that we will use for rocket exhaust valves will come as a result of the study that we are conducting out there now. Unless someone comes up with something better in the meantime, this is the only one that we have right now that is compatible with these kind of systems.

Ricca: I would like to make one comment about the talk on the fluorine testing and that is regarding contractor #2 which was not Rocketdyne. No. 2 was General Dynamics Convair at Sycamore Canyon. Its somewhat interesting to note some of the pieces of information that originally SSD did request of the contractor which did not forthcome. I'll give you some obvious reasons on it not being forthcoming. One I specifically noted on there was evaporation rates of liquid fluorine. This was one of the objectives of the test which obviously they could not have delivered prior to siting the facility and doing the test. So as you guessed this might be somewhat of a defense for GDC's slowness of response to the SSD request of providing information for siting.

Channell: I'm afraid that contractor #2 was not General Dynamics.

Christofano, Hercules: Will the information that was contained in the talks this morning be presented in some published form so that it is available for review?

Lowell: We have recorded it on the tape and it will be published in the Seminar Minutes.

Applegate, Boeing: Are you pretty well convinced that the emergency exposure limits that you mentioned in the paper are the latest thinking and the ones that the contractor should follow in evaluation of liquid fluorine firings?

Channell: No I am not, I am currently checking into this. However, these are the latest figures that I have on hand.

Applegate: The ones you're using now you said were revised from the National Research Council?

Channell: Yes, these came from the National Research Council, however, I was not the person who got them. A lot of the detailed background on this, as was indicated, was not available to me and I pulled the information strictly from files.

Applegate: I understand there's quite a bit of discussion and controversy on it even within the committee that established the limit. I think its something we probably shouldn't be too firm on.

Channell: The last one shown there could very well be that which would be imposed but I am not definite in my comment on that particular thing at this time. Give me another 2 or 3 weeks and I will be.

Milne, PMR: I have a couple of questions for Capt. Kittilstad. One thing I missed noting this morning was any particle size information from your experiments and I wonder if you have any data on the range of particle size that you got from these motor tests with a percentage or a fraction that might be in the respirable range?

Kittilstad: We have particle size work that is programmed into this but on the other hand there is a considerable volume of information that's also being collected - I should say the primary intent of the material is for ballistics efficiency and combustion efficiency work. We have had contracts with a number of people including Atlantic Rsearch and Hercules. Its in the written literature on combustion already on the particle size and chemical composition from rocket motor firings. If I can make a generalization of this data right now, there is some controversy involved as to techniques and this type thing, as to validity of the data, but I don't think the controversy rises as much from the particle size knowledge that we require in industrial hygiene as much as it would be for ballistics efficiency purposes. From good combustion I think we can essentially say that probably all the material was below 5 microns and I think we can consider it as all being within the respirable range. There is even some bit of controversy about this but not as much as particle size coming from the accident situation where we have only had one experiment that I know of and this was with a contract with Hercules. Essentially in this program we took slugs of beryllium propellant, fired them and detonated them, and after they fired some motors in this contract inside a tank, collected the material, did particle size analysis and chemical analysis on the material. There is some bit of controversy in this particular program as to the validity of the data. We had some experimental problems as far as rust in the tank and things like this which clouds some of the data that we've accumulated but there is a considerable difference when you take this body of experiment that we got out of this contract in the difference between motor firings, detonations and burns. I hate to generalize too much on this data. To give you an idea in the difference in the magnitude between motor firings and what you would expect from a burn, I would give you a conservative estimate right now that probably 80% of the material in an accident from a burn situation as we conducted them in these experiments is probably above 10 microns and the remainder is below 10 microns. I can't give you any better answer than that.

Milne: I think this partially answers my next question which was the relationship between particle size and the amount of fall-out that you get from the plume in near distances down-range from the exhaust.

Kittilstad: I know what you are driving at and this was one of the reasons we conducted some of these tanks in the test, there was some speculation that if you apply Stokes Law to some of

these diffusion equations you should get a larger fall-out of material within the first few hundred meters of the test. I have no data that tells us, I can't answer your question. But I would generally say that we are primarily concerned even if its above 5 microns. Between 5 and 10 microns - the effects from Stokes Law is not that great and with a normal firing I don't think we would get much material above that size.

Peterson: Gentlemen, I would like to comment that this discussion this morning did nothing more than scratch the surface of air pollution problems. It wasn't the intent, I don't believe, for the panel to get involved in the tremendous amount of detail regarding it. Rather to tell you a little about what's involved in the law, to describe briefly the operations that are being conducted to evaluate and control some of the pollution problems resulting from missile firing operations. I think we've pointed out that pollution is a problem in this field that we have to continue to vigorously pursue. There's much information that we need yet, before we can know all the answers, but I believe that we have a good program started and with the continued cooperation of the various Federal agencies, with management and with the scientists, I think we can certainly continue to test propellants with reasonable safety. Thank you very much.

SAFETY TECHNIQUES FOR RESEARCH AND DEVELOPMENT ON NEW HIGH ENERGY OXIDIZERS

Dennis G. Nelson
3M Company
St. Paul, Minnesota

The Contract Development Laboratory at 3M Company has been in existence for more than five years. During this time, a considerable background in safety techniques has been accumulated for characterization and development of new high energy oxidizers under a series of Advance Research Projects Agency contracts. Due to the variety and initial uncertainty of the hazards involved in handling energetic solids, liquids and gases, these techniques must necessarily be versatile and comprehensive.

The majority of our Contract Development safety techniques are applications of the following principles:

1. Safety via miniaturization.
2. Safety via dilution.
3. Safety via remote protection.
4. Safety via simplicity of operation.
5. Safety via testing and analysis.

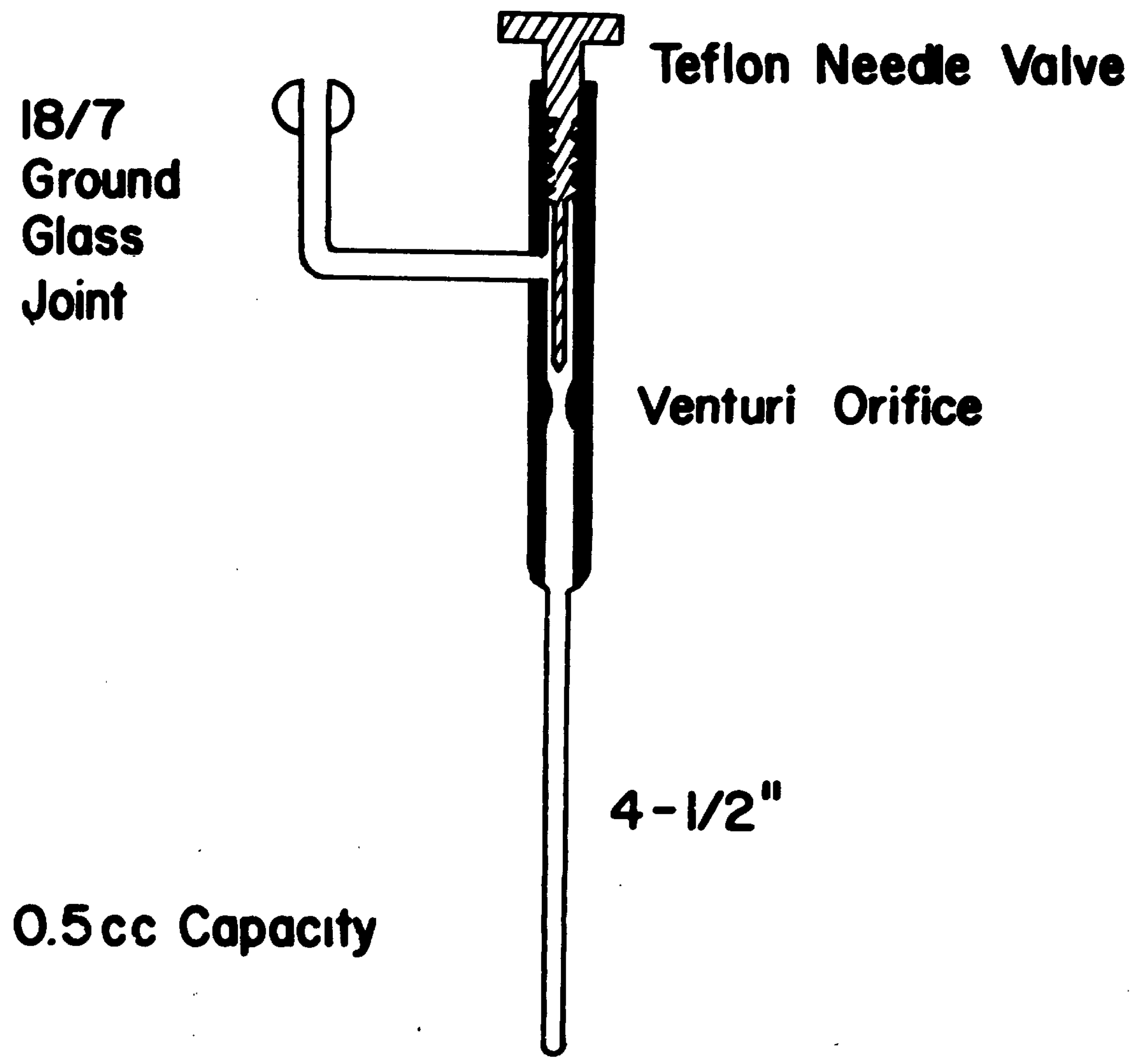
Safety techniques have been developed for research, development and small-scale production, as well as complete chemical analysis and testing of high energy oxidizers. In addition, a continuous comprehensive safety program is maintained throughout the area which reviews current projects and sets up safety standards for new projects.

Research Techniques

The typical flow of a 3M Contract Development Lab program is from research through development and small-scale production. Our project safety program is organized in the same manner. The bulk of safety data is accumulated at a very small scale to be later applied to larger scale operations. Figure 1 shows a schematic diagram of a nuclear-magnetic resonance tube, a basic tool for oxidizer research at 3M. These tubes are often used for screening reactions by combining reactants in the tubes and analyzing for reaction products. A quantity as small as 0.2 cc of liquid in this tube with an oxidizer concentration of 10-20% is sufficient for detection.

Figure 2 shows one of the NMR detection units at 3M. In particular, note the enclosed 1/2" Plexiglas glove box for the operator's protection during sample injection, analysis, and withdrawal. This unit is capable of detecting 1/2 mmole (100-500 mg) of a fluorine-containing

FIGURE I
NUCLEAR MAGNETIC RESONANCE TUBE



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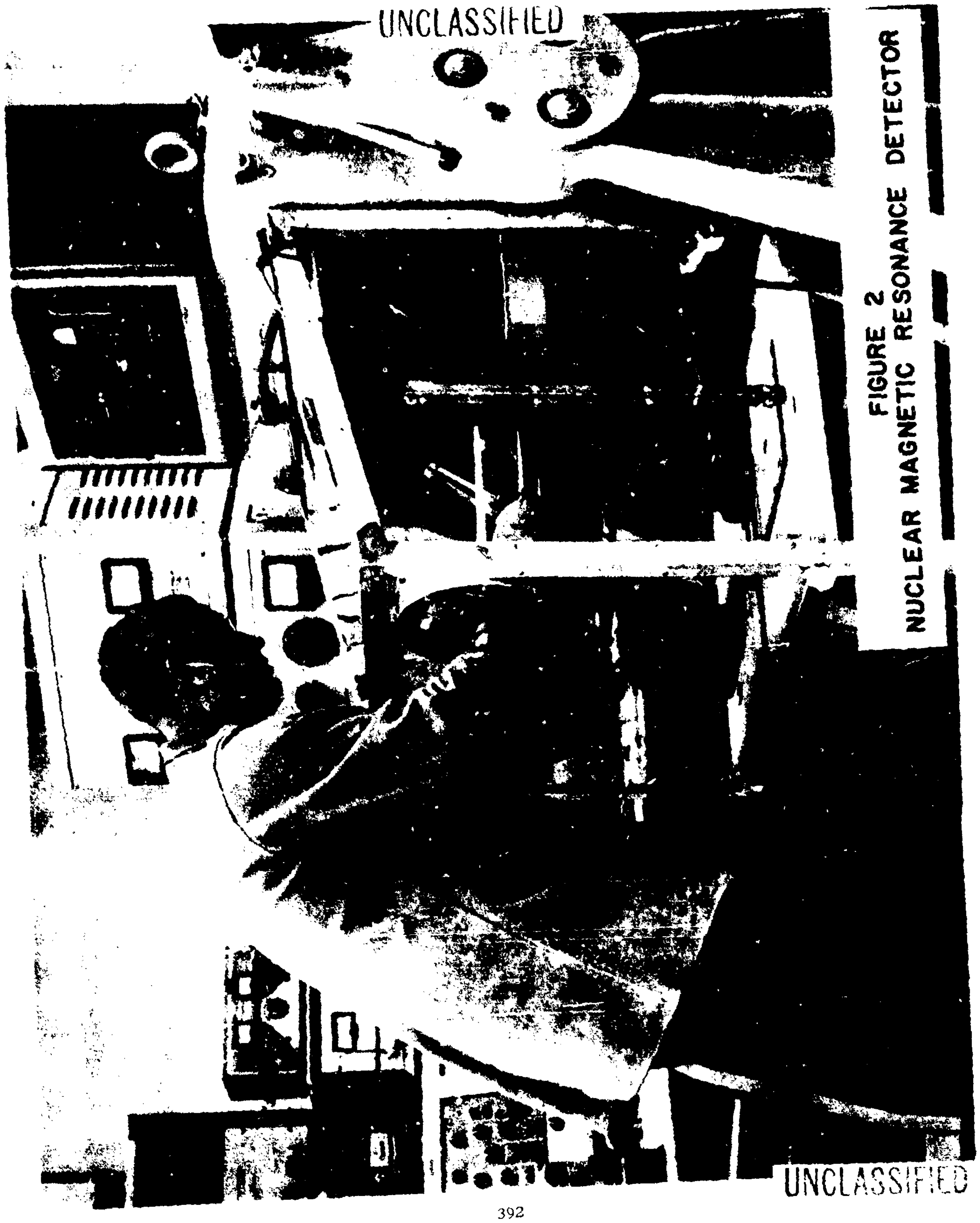

FIGURE 2
NUCLEAR MAGNETIC RESONANCE DETECTOR

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oxidizer. This minute quantity of explosive material, along with the relatively few manipulative analytical steps required, make this a safe and versatile tool for the basic researcher.

Slightly farther along in our research-development sequence is the 20 ml "seal-less" reactor shown in Figure 3. These small units are useful in extending NMR data into basic processing information: optimum reaction conditions, conversion rate, as well as identification and resolution of sensitive processing steps.

The glass reactor body was made from a standard 1" Pyrex double strength flanged pipe cap. The 7/8" Teflon coated magnet and magnetic stirring unit are also standard commercial items. The Kel-F support rod prevents the magnet from being thrown out of position. This unit develops 200-300 rpm and is suitable for dispersing two-phase liquids, gas-liquid or dilute liquid-solid systems. Its environmental capabilities are from full vacuum to 20 psig, -90°C to greater than 200°C.

As with the NMR tube, the relative size and simplicity of these units make them adaptable to oxidizer processing studies where relatively little safety data is available. For rapid processing studies these reactors may be safely placed in series such that they are individually barricaded but still accessible to an operator wearing protective clothing. Figures 4 and 5 show photographs of such a multiple hookup. Figure 6 shows a typical glass rack overhead system for operations of this type. In event of an explosion, normally only the glass components of the system are destroyed. In most instances operations may be quickly resumed after replacement of standard components.

The 300 milliter stainless steel reactor shown in Figure 7 is the largest scale system still considered in the realm of research at the Contract Development Laboratory. The picture shows the reactor housed in its separate barricade which can be isolated from the rest of the system. A glass overhead system is still accessible to an operator clothed in protective gear.

Analytical Tools for New High Energy Oxidizers

Essential to the safe operation of an oxidizer research and development program is a complete set of analytical tools. Both rapid in-process analyses and supplementary analytical techniques are required. Probably the most widely used tool for both in-process and supplementary analyses at the Contract Development Laboratory is the gas-liquid chromatograph. As with previous devices, the micro-liter sample size and the few manipulative steps required for GLC analyses make this a safe, versatile analytical tool. A schematic diagram of a special GLC hookup is shown in Figure 8. A photograph is presented in Figure 9. This system has been designed so that both identification and isolation/purification of two condensible components is possible. The enclosed 1/2" Plexiglas

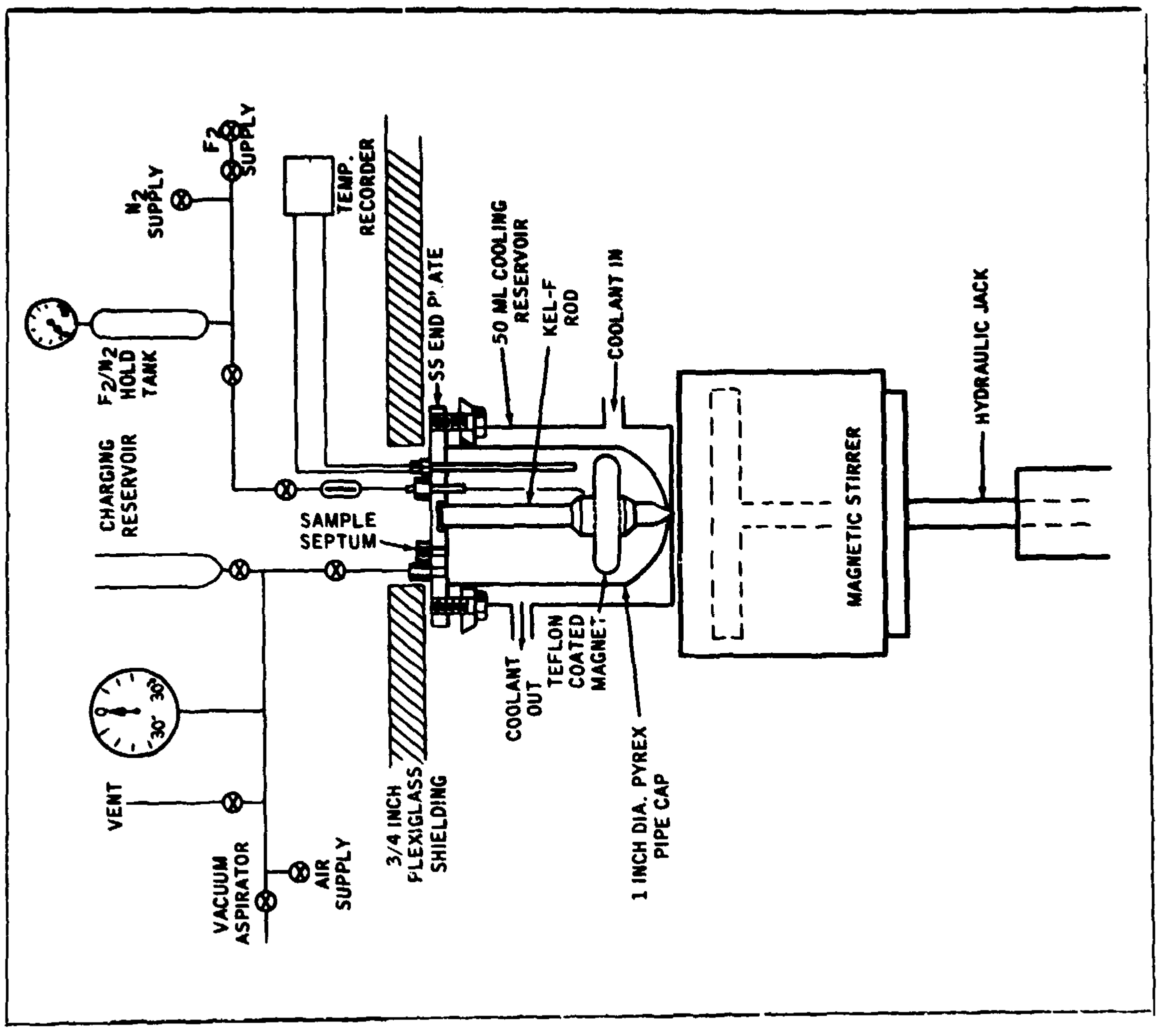

FIGURE 3
20 ML. SEAL-LESS REACTOR

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FIGURE 4: MULTIPLE SEAL-LESS REACTOR INSTALLATION

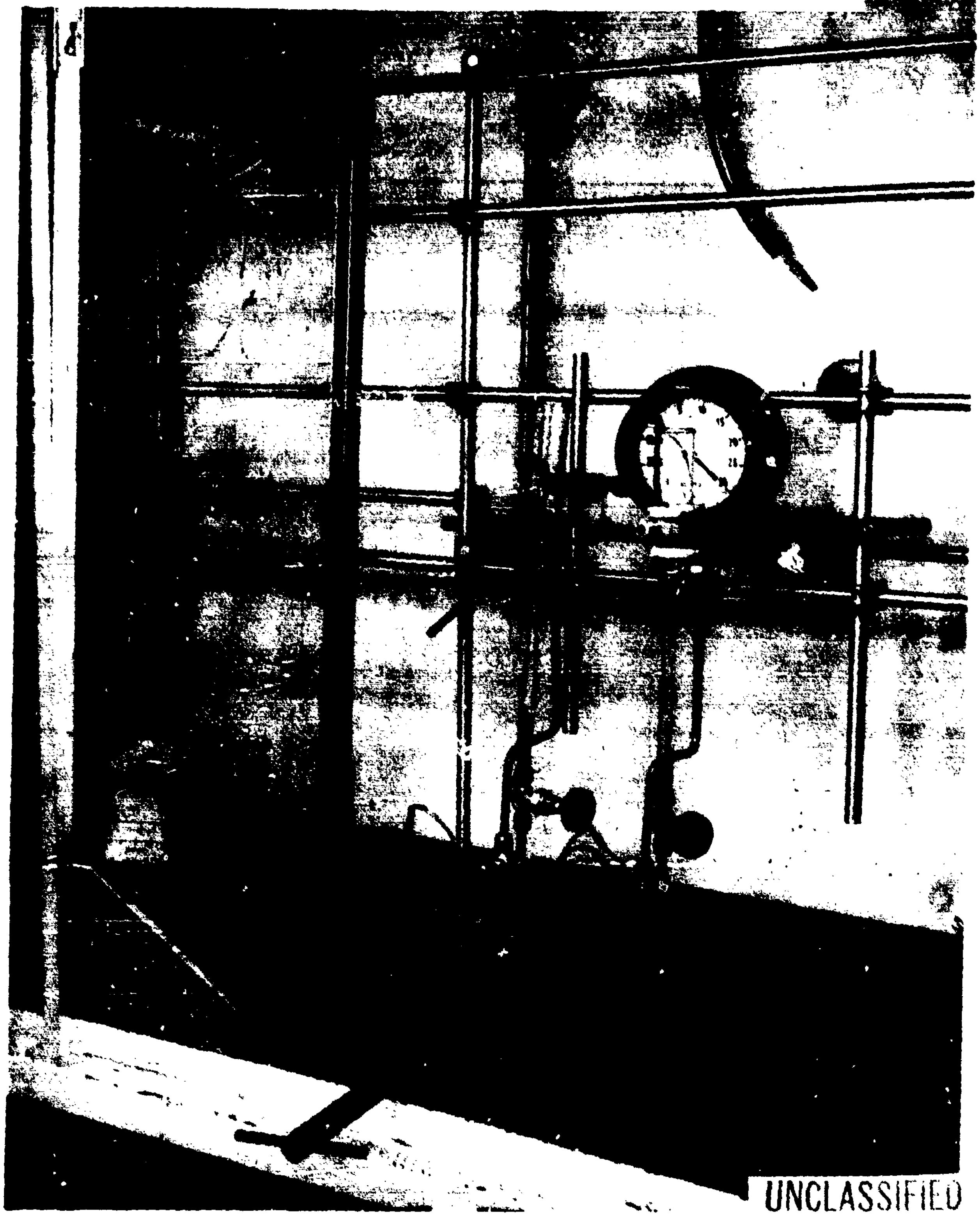

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FIGURE 5: OPERATION OF MULTIPLE SEAL-LESS REACTOR

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FIGURE 6: SEMI-REMOTE GLASS RACK

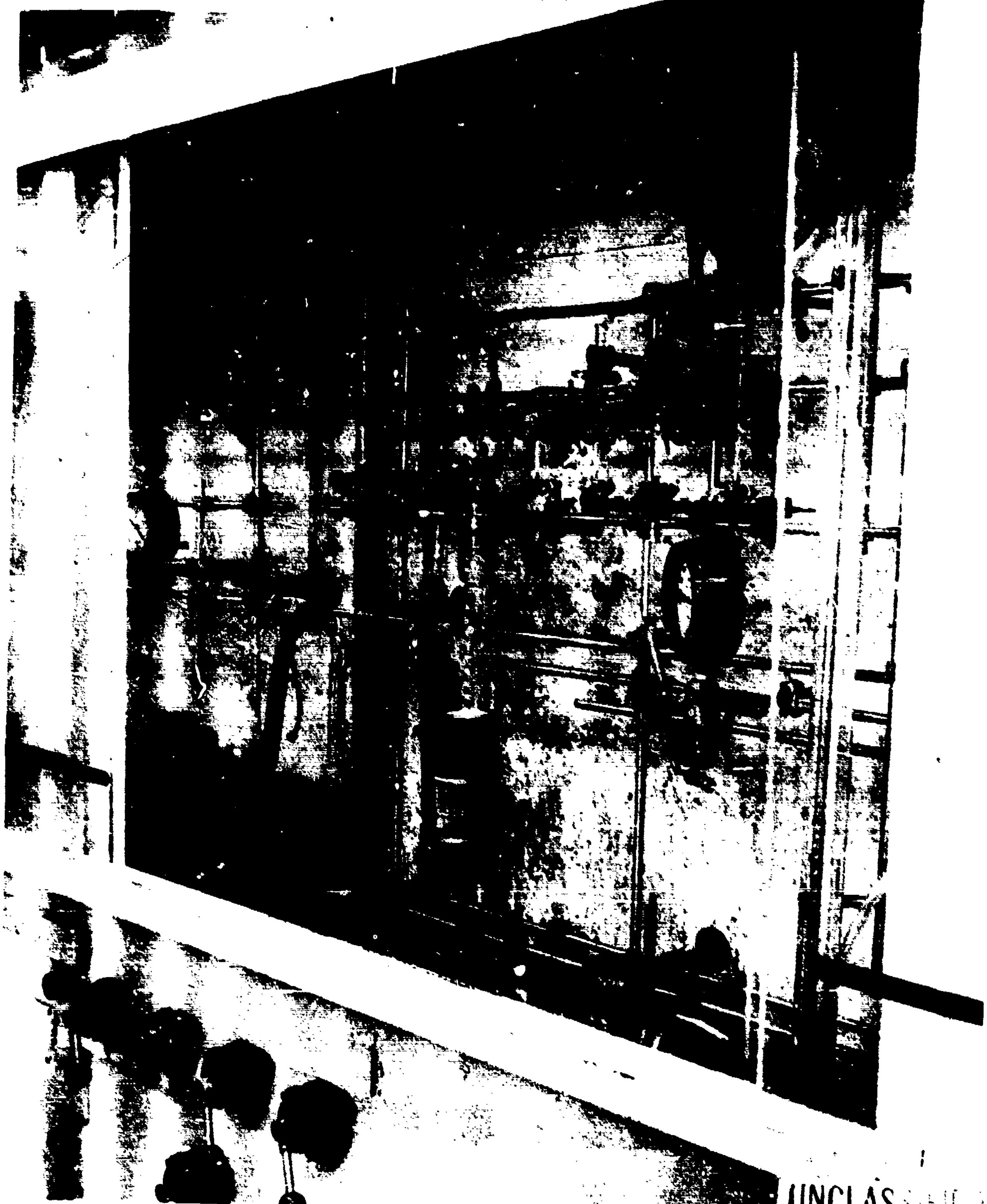

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FIGURE 7
300 MILLILITER REACTOR

FIGURE 8

GLC - TRAPPING SYSTEM SCHEMATIC DIAGRAM

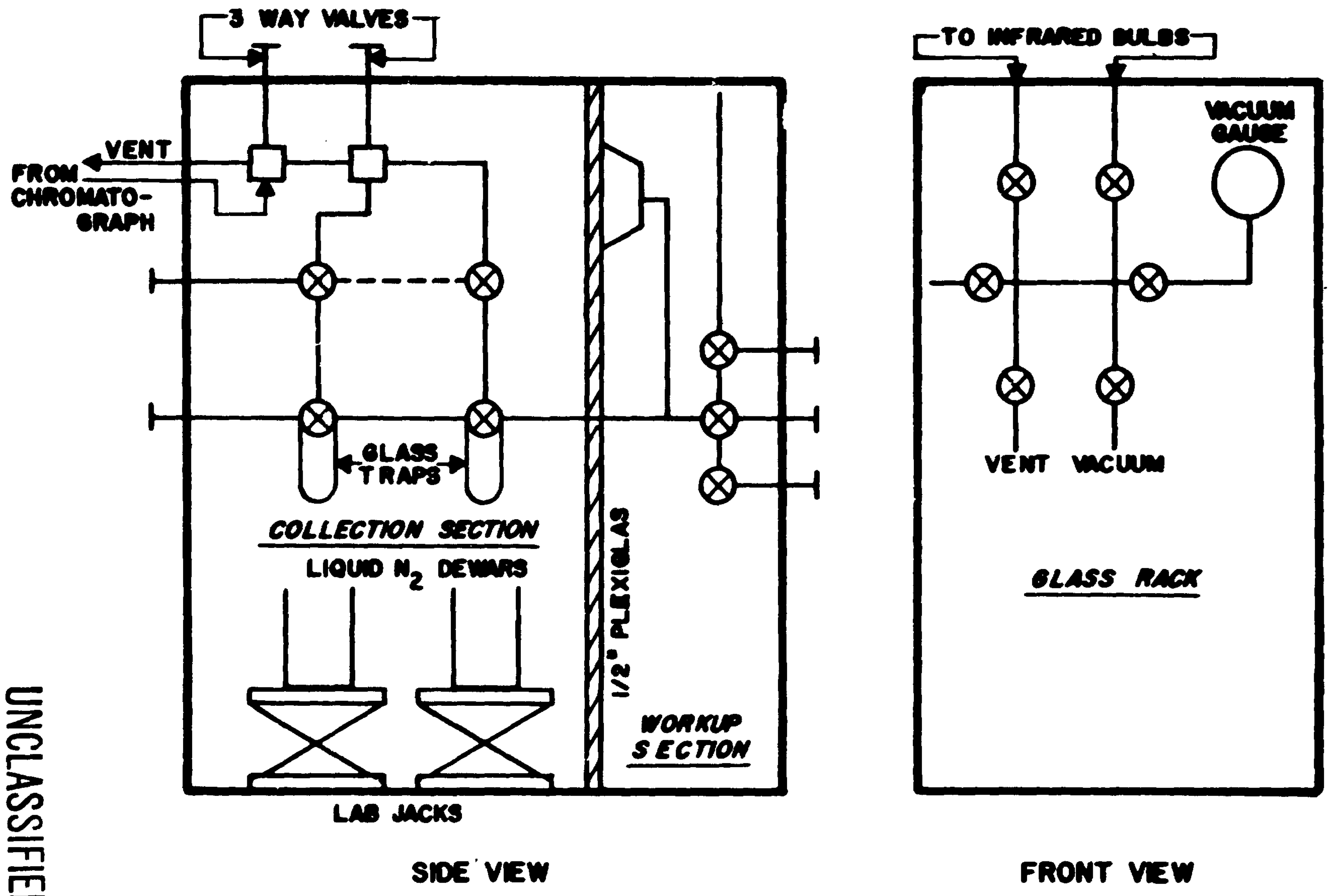

FIGURE 9

GLC Trapping System

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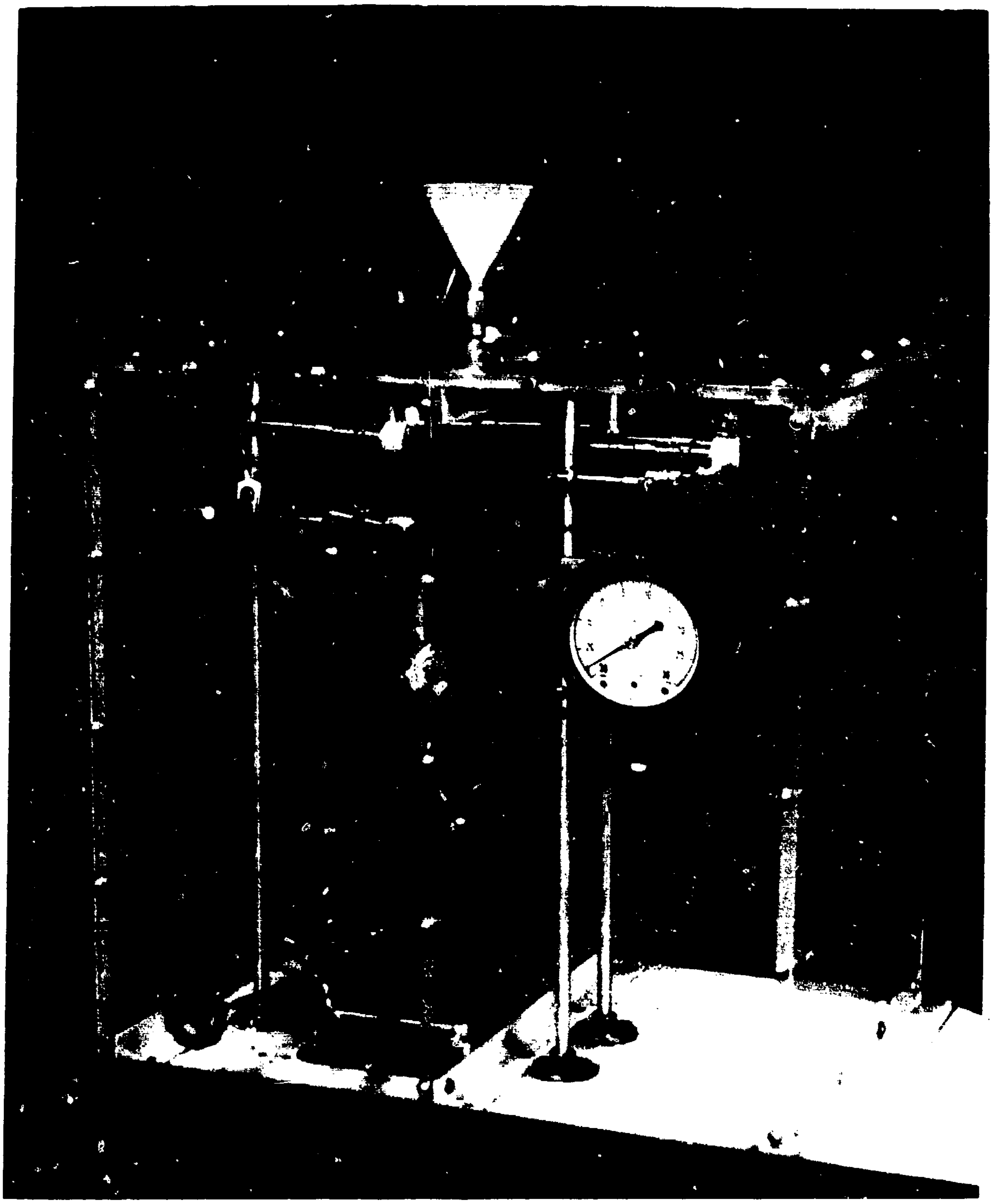

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box, appropriate shielding for the quantity of oxidizer involved (normally less than 50 milligrams), protects the operator while allowing full vision of the operation. The operator is able to monitor his product stream with the chromatograph and then switch the three-way valves from vent to trap when a desired product peak appears on the recorder chart. Following isolation in the liquid nitrogen cooled glass traps, a product may be expanded into a separate section of the box where it may be collected into bulbs or vented. An I.R. gas sample is also possible at this point. A Beckman Megachrom Preparative Gas Chromatograph, operating on this same general principle, is also available for larger scale purification of samples, up to 50 grams per day.

For development and small-scale production facilities, a series of quantitative tools are required that can be used remotely. Such a list of simple, versatile measurements that can be made without entering a bay where a dangerous chemical operation is in progress includes:

1. Pressure-volume relationships for gases.
2. "In-line" graduates for liquids.
3. Titration systems for chemical reactions.
4. Remote micro-sampling systems for liquids and gases.

Figures 10 and 11 show the details of a liquid/gas oxidizer sampling system connected directly to the reactor inside the bay. This system was designed and constructed by 3M personnel for safe, reliable, remote samples of extremely hazardous reactor charges. The system was designed so that a maximum of 1 gram of liquid oxidizer could be present in the sample box at any one time. The liquid sample line is cooled right up to the sample box to insure a sample representative of the reactor. Special washers around each of the orifices prevent any damaging shrapnel from escaping the box. Using this device, it is possible to take "in-process" samples at a safe level from a reactor containing up to 1/2 lb. of hazardous oxidizers.

In addition to in-process analyses, a series of versatile and comprehensive supplemental analyses have been developed at 3M for analysis of gaseous liquid and solid oxidizers (Figure 12). All of these analyses can be run conveniently on a milligram scale such that conventional protective clothing, i.e., leather coat, face shield, ear plugs and gloves, is sufficient for the operator's protection.

Development

In contrast to a huge Atlas motor, a quart and a half of propellant solution is a relatively small quantity. However, in terms of potential destruction, this development quantity is more than enough to create a meaningful human hazard. Beginning at the development stage, all subsequent oxidizer processing is done completely within

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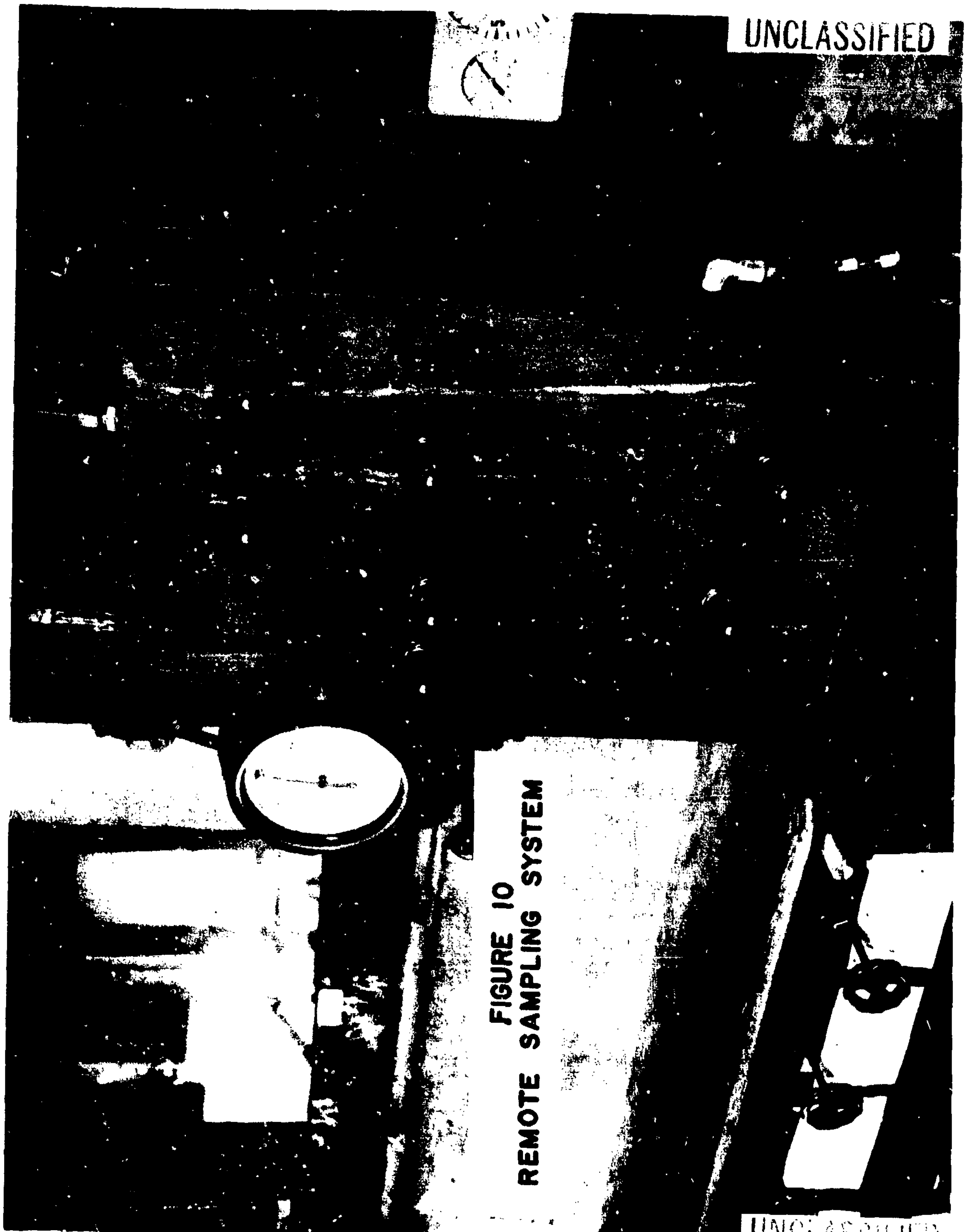

FIGURE 10
REMOTE SAMPLING SYSTEM

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FIGURE 11
REMOTE SAMPLING SYSTEM-SCHEMATIC DIAGRAM

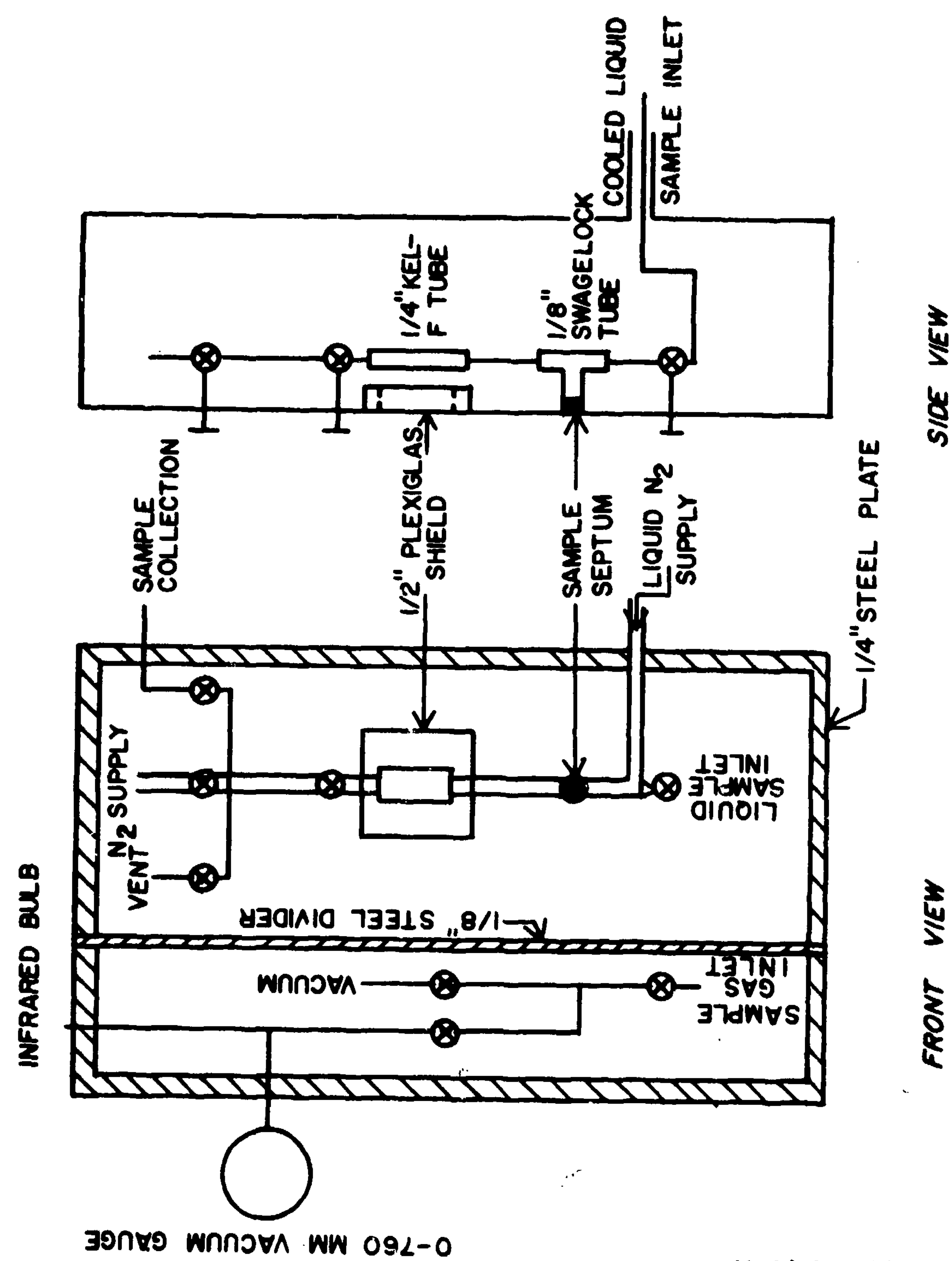

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FIGURE 12

TABLE OF MILLIGRAM ANALYTICAL ANALYSES

ANALYSIS	*QUANTITY*
OXIDIZING POWER	15 MILLIGRAMS
INFRARED ANALYSIS	.2
EQUIVALENT WEIGHT	50
ELEMENTAL ANALYSIS	
Carbon	50
Fluorine	.2
Nitrogen	20

remote location facilities. Almost without exception, a twin bay concept is used for all oxidizer development and small-scale production. The operator is separated from his material by 14" reinforced concrete walls. He views the operation through two thicknesses of 4" Plexiglas separated by a dead air space. Figure 13 shows a photograph of a typical reaction bay with the direct drive rods and flexible heavy-duty cables which are connected to process valves. Figure 14 shows the other half of the twin bay where the operator conducts all the manipulations. In addition to the flexible cables and direct drive rods, the overhead switch panel provides power and control over all electrically driven equipment within the reaction bay. The services that are available within the reaction bay include: hot and cold water, steam, vacuum, pressure, inert gas and fluorine.

Although process explosions are not frequent at the Contract Development Laboratory, we treat our material as though explosions occurred every day. Therefore, our facilities plan for the worst to happen and direct the explosion where it can do the least damage. Figure 15 shows a typical blast door which protects all personnel on the interior side of the reaction bay. Figure 16 shows the flimsy blowout door on the other side of the bay which permits any sudden over-pressure to relieve itself where it can do no harm.

Since remote, twin bay facilities of the type described above are at a premium, they must be efficiently utilized. For this purpose the versatile cart and cable technique has been developed at the Contract Development Laboratory. Using this system, process equipment for specific applications is mounted on portable laboratory carts before transferring to reaction bays, thus expediting effective use of remote facilities. Figure 17 shows a photograph of such a system before installation. Should an operation be terminated or process equipment damaged, the cart is removed from the bay and the next system is wheeled in. In most instances repairs and/or installations consume only a day or two of bay time.

Another concept that is applied wherever possible for safe yet efficient operation is the use of readily available, easily modified equipment. For example, conventional glassware is used wherever possible for processing, thus:

1. Minimizing damaging shrapnel in case of explosion.
2. Allowing rapid replacement of key equipment.

Similarly, conventional valves, fittings, tubing, and other processing equipment are used wherever feasible. In addition, process equipment and techniques are evolved from simplified systems as the characteristic hazards of particular oxidizers are determined.

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FIGURE 15: TYPICAL REACTION BAY

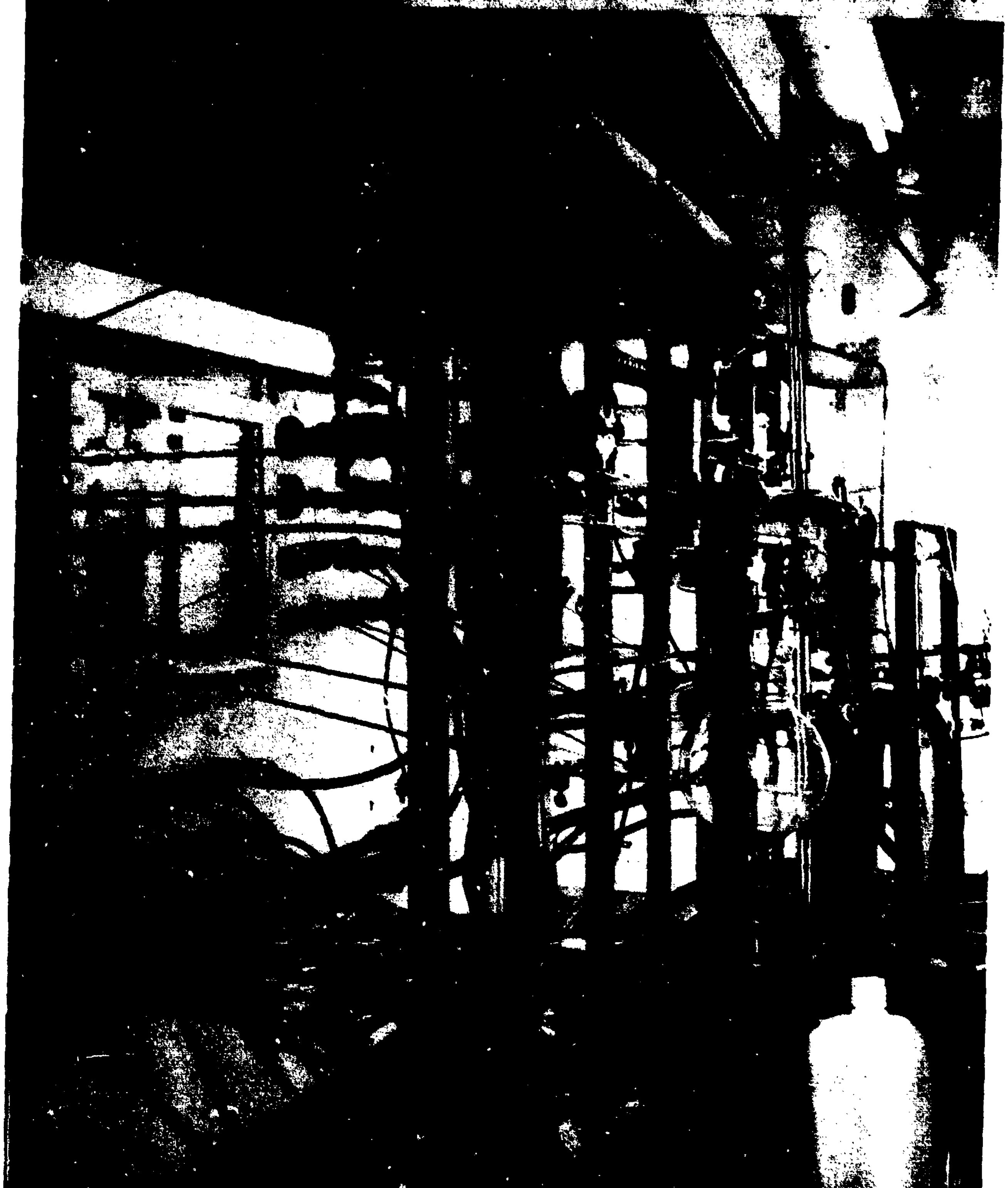

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FIGURE 14
TYPICAL OPERATOR'S BAY

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FIGURE 15: REACTION BAY BLAST DOOR

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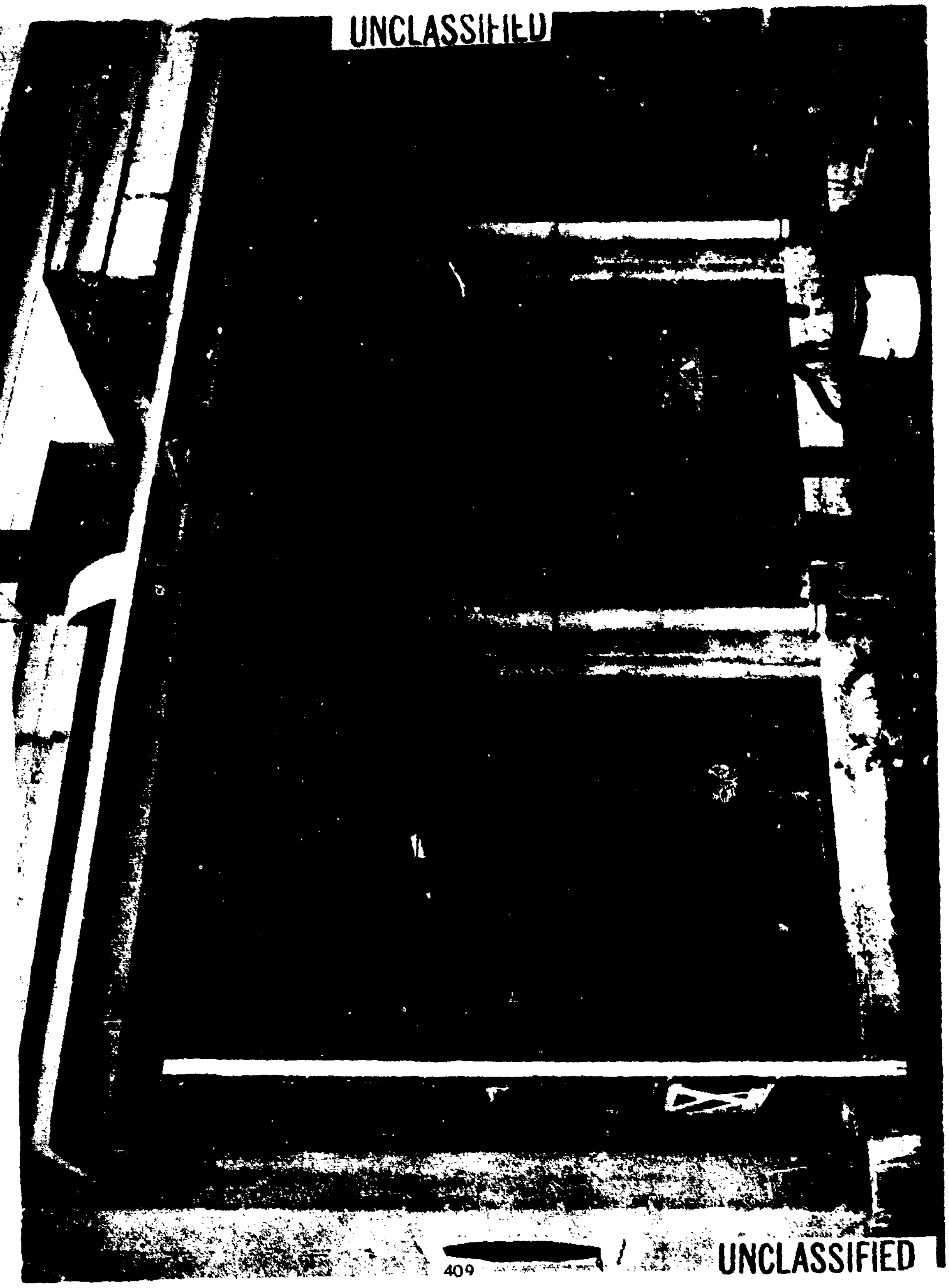

FIGURE 16: REACTION BAY BLOWOUT DOOR

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FIGURE 17
CART AND CABLE APPARATUS

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A fourth concept applied to oxidizer handling is the use of flow processes to replace batch processes, particularly where scale-up data is desired. With this method, large quantities of oxidizer solutions are never allowed to accumulate, but are continually transported and mixed through a series of pipes or tubes.

Safety by Dilution

A good rule developed over the years at 3M is to avoid whenever possible the handling of pure fluorochemical oxidizers or highly concentrated solutions of gaseous liquid and solid oxidizers. The diluents and solvents commonly used at the Contract Development Lab are inert gaseous diluents, fluorochemical solvents and conventional organic solvents. A complete history has been accumulated regarding the concentrations required for safe handling and the general processing of such solutions.

Testing Techniques

An oxidizer testing program which runs concurrently with each significant development project is an essential part of the Contract Development Laboratory's overall safety record. Before an oxidizer or intermediate may be handled by operator personnel, a thorough safety evaluation of the material is made. Determinations such as shock sensitivity, explosive limits of oxidizer solutions, vapor pressure determinations in solution, and solvent compatibility, as well as specialized tests where required, are common to each new oxidizer which comes into the laboratory. In addition, the Contract Development Lab works closely with the United States Bureau of Explosives on test programs involving the shipment of our oxidizers and oxidizer solution. Toxicity screening of oxidizers is a recent addition to the safety program at 3M Company.

Small-Scale Production

By most standards, oxidizer production equipment at the Contract Development Laboratory seems quite small indeed. Our average oxidizer reactors range in size from about a 1-1/2 quart capacity to approximately 10 gallons. Our approach has been to expeditiously produce small quantities of fluorochemical oxidizers for propellant evaluation, while retaining a high degree of versatility. As is found throughout our development facilities, the twin bay concept is used throughout production. Figure 18 shows a photograph of a double reaction bay separated by an operator's control bay. With this facility a single operator may conduct two simultaneous operations on either side. Again the cart and cable technique is used as is the concept of using readily available, easily modified equipment. Figures 19-21 show the "Barricade within a Barricade" concept applied to small scale production. Moderate explosions have occurred within this 10 gal. reactor without causing any other damage in the bay. With these kinds of facilities, up to ten pounds of high energy material may be prepared at one time.

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FIGURE 18: DUAL OPERATOR'S BAY FOR SMALL SCALE PRODUCTION

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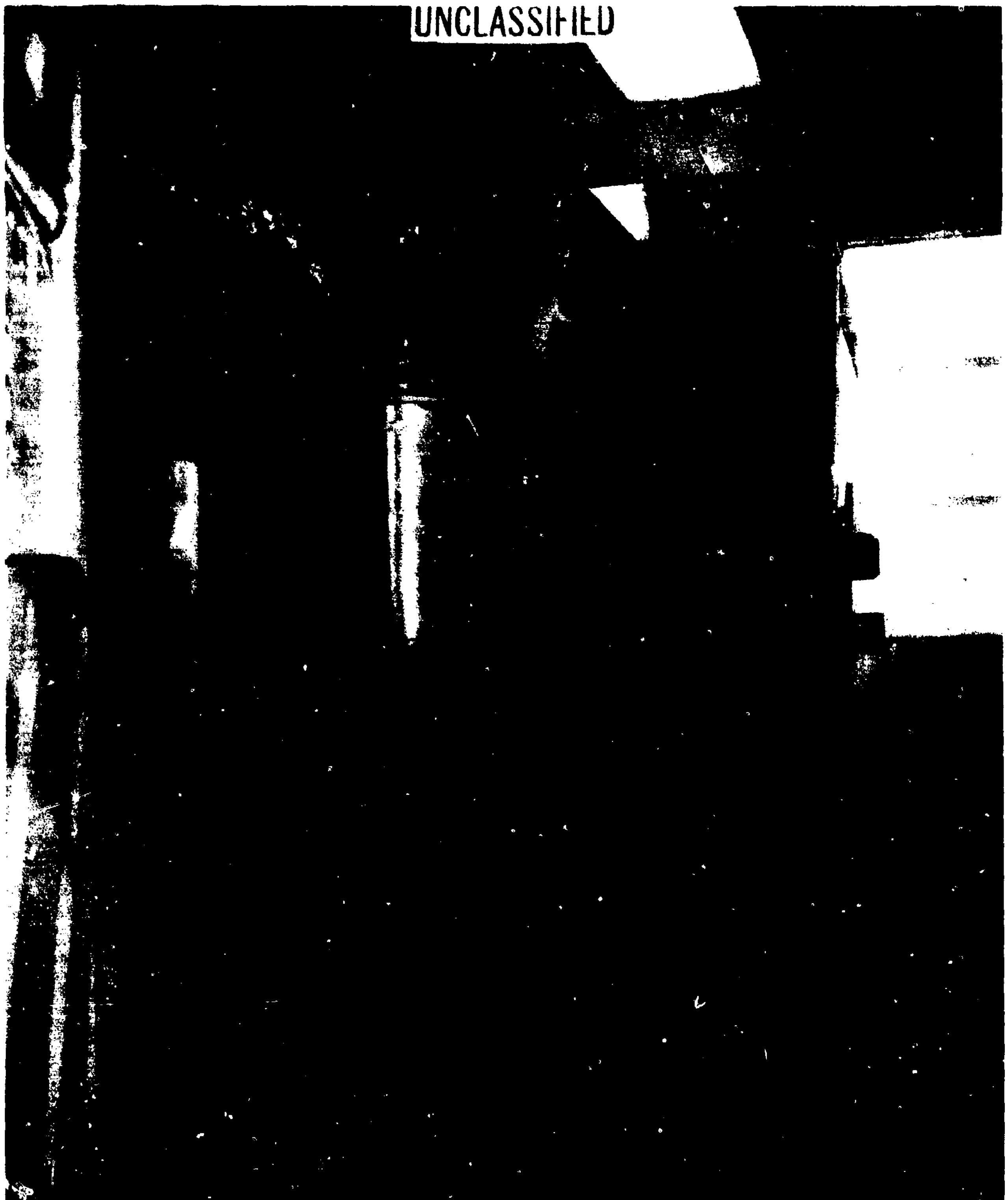

FIGURE 19: BARRICADE WITHIN A BARRICADE

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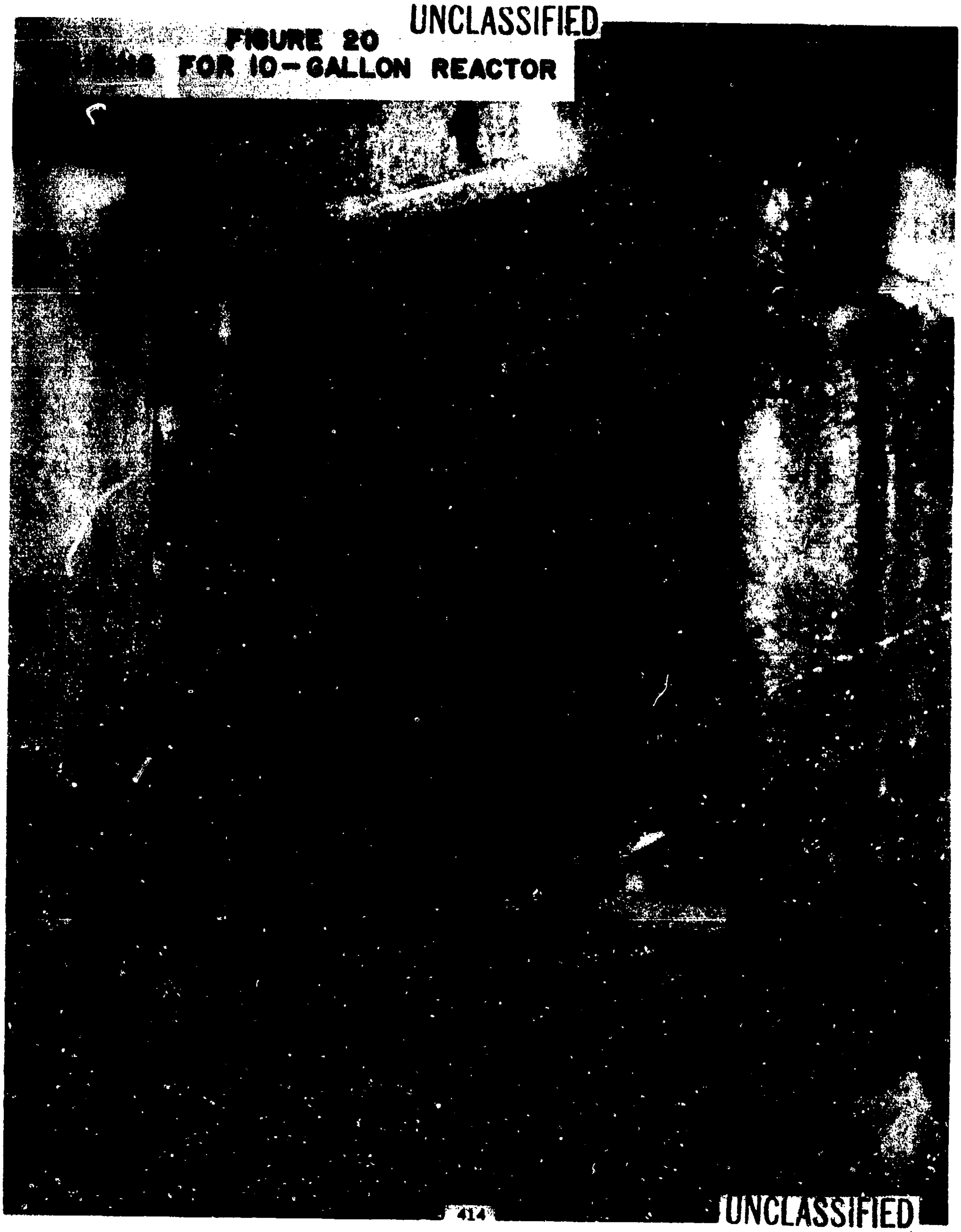
FIGURE 20
[illegible] FOR 10-GALLON REACTOR



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GALLON PRODUCTION REACTOR

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Although most facilities at the Contract Development Laboratory are designed for small quantities of materials, basic raw materials are handled in bulk quantity wherever possible. Figure 22 shows an example of this concept. This unit is a double sealed, liquid fluorine system capable of containing 5,000 lbs. of liquid fluorine. The entire unit is below grade resting on two feet of coarse limestone which would act to neutralize any escaping material. An outer jacket of liquid nitrogen surrounds the fluroine, as well as a vacuum jacket beyond that. Primary and auxiliary shut-off valves are provided which may be operated remotely.

Safety Program

If, in spite of all the precautions described earlier, an accident does occur, we are extremely well prepared. Figure 23 shows a typical hall-way outside our operator bays complete with safety showers, fire stations, fire blanket, protective equipment, fresh air mask and emergency exits. Figure 24 shows a close-up view of the emergency fire station complete with CO_2 cylinder, dry chemical extinguisher, water extinguisher, and an extinguisher for metallic fires. An emergency horn is mounted on the wall for effective evacuation alarm. In addition to the material safety precautions, a vigilant safety inspection program is maintained. A rotating safety committee has been formed which meets once a month and more frequently as the situation demands. In fact, each major project is reviewed for its safety considerations and a monthly inspection of each building is accomplished. Close cooperation with our divisional safety engineer is maintained and specialized lectures and films are sought to maximize our personnel's safety consciousness.

Although fluorochemical oxidizers must be considered highly hazardous chemicals by almost any definition, we like to think that our vigilant safety techniques at the Contract Development Laboratory make their processing a routine matter. As long as safety is foremost in every person's mind, we can expect this operation to continue as any other normal chemical processing. In fact, we like to feel that with our extreme cognizance of safety, that this oxidizer operation is actually less hazardous than many conventional chemical processes where safety is not emphasized to as great an extent.

*****

Dr. Damon: To set the record straight, let's understand the statement that Mr. Nelson made - the U.S. Bureau of Explosives is not a U. S. Government organization. Please don't send it to Washington that way, otherwise I get it and have to send it to New York.

Nelson: Excuse me.

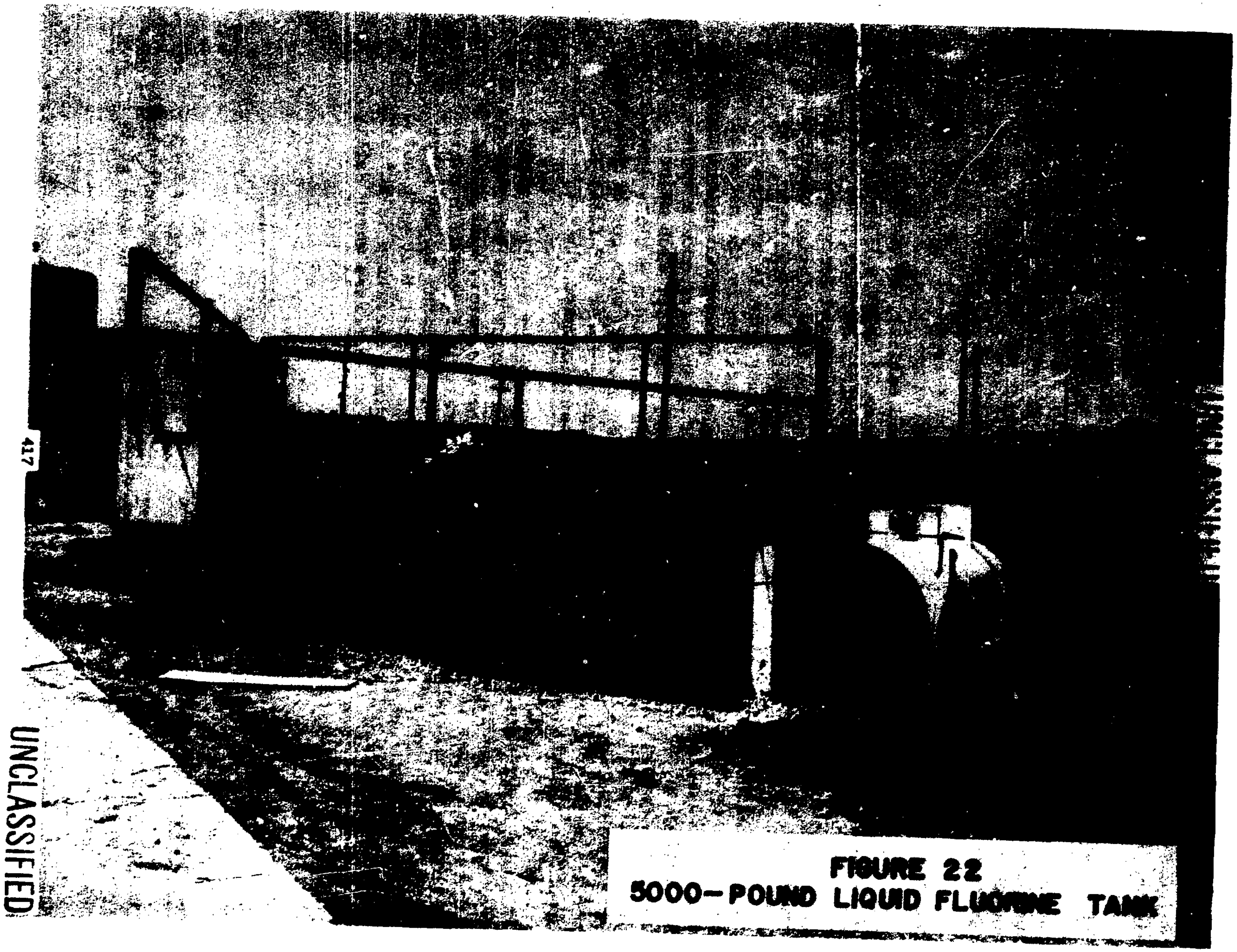

FIGURE 22
5000-POUND LIQUID FLUORINE TANK

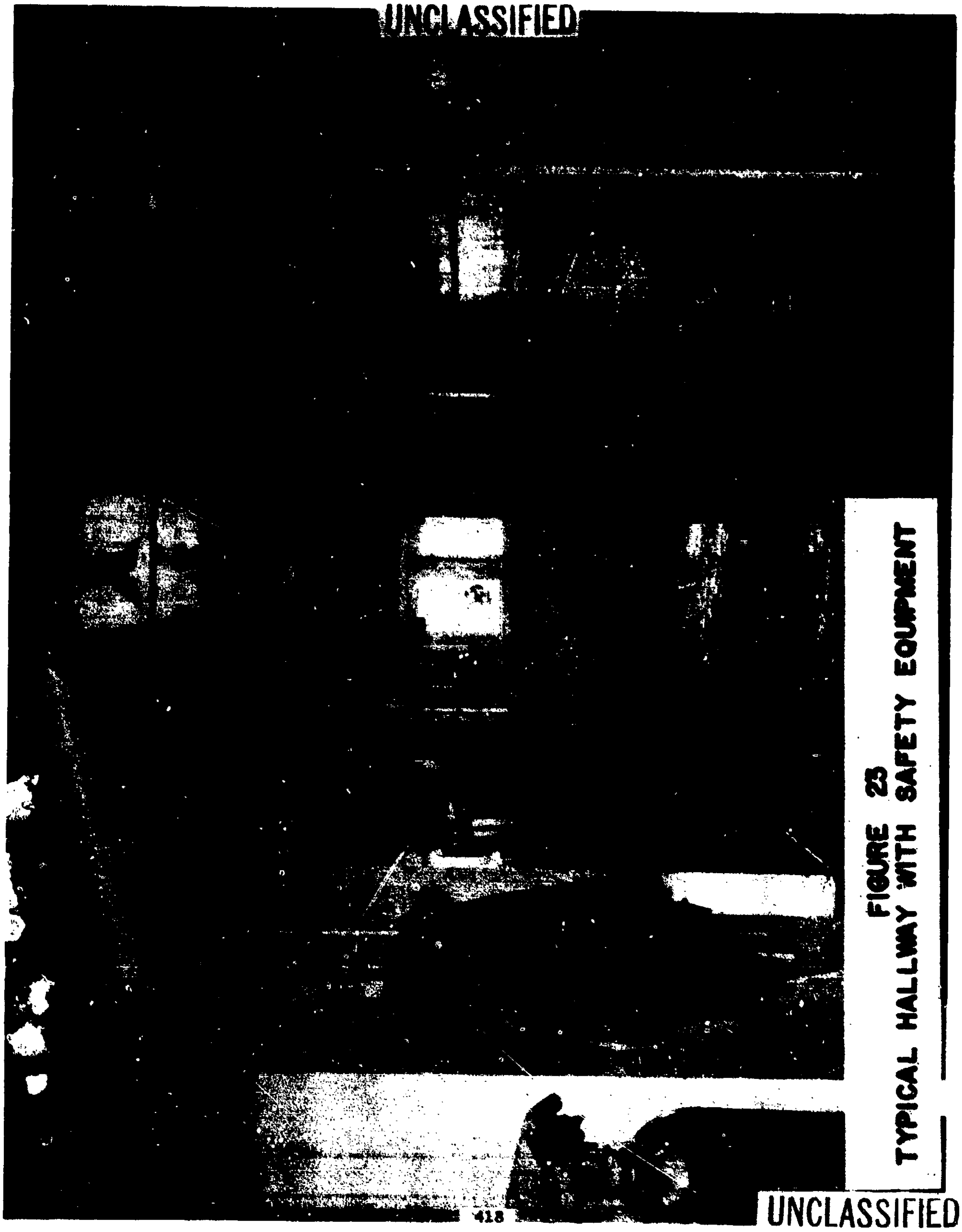

FIGURE 23
TYPICAL HALLWAY WITH SAFETY EQUIPMENT

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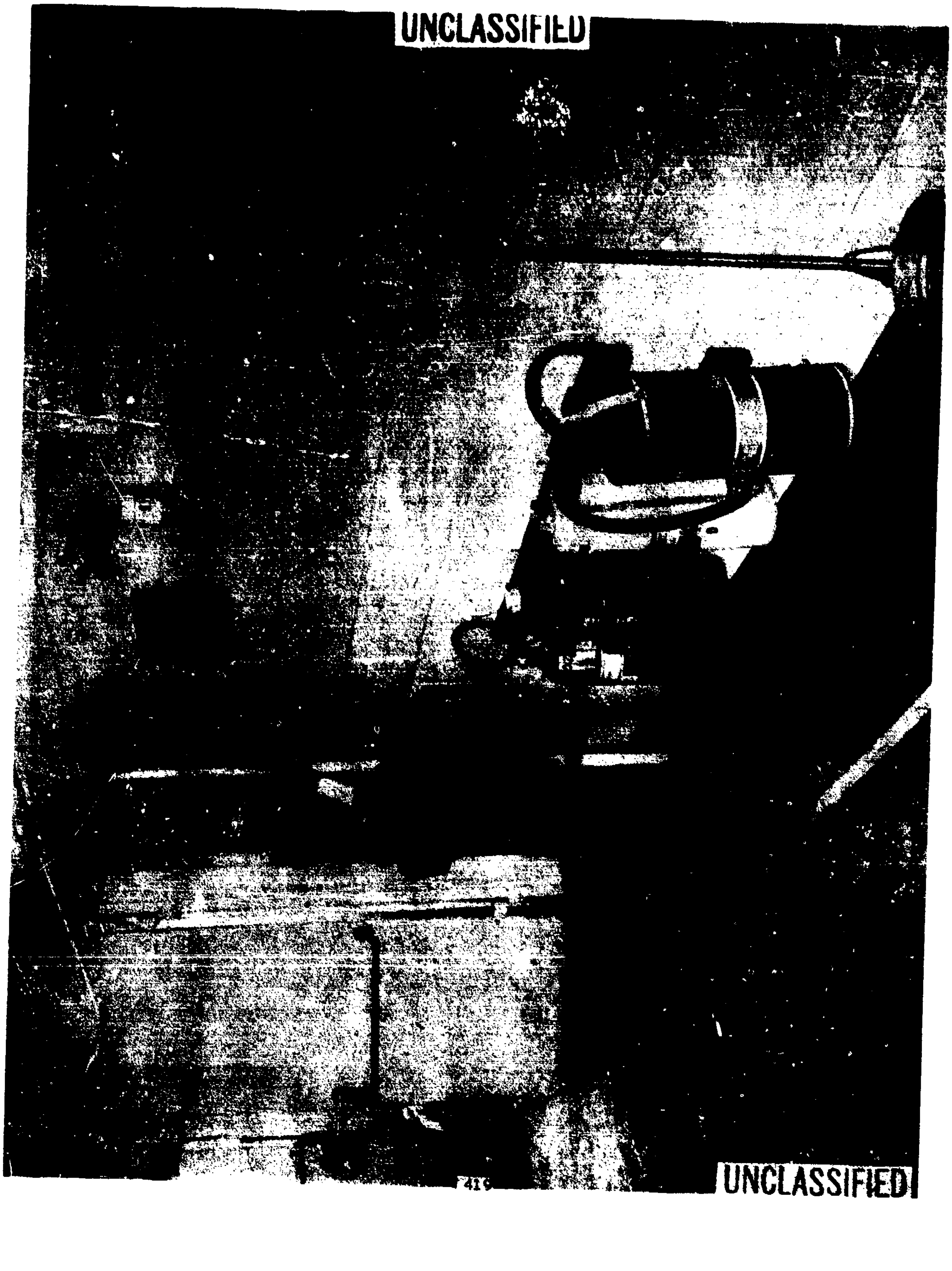

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SAFETY CONSIDERATIONS

HYBRID PROPELLANT ROCKET MOTORS

Dr. E. A. Weilmuenster
United Technology Center
Division of United Aircraft Corporation
Sunnyvale, Calif.

ABSTRACT

In the past 20 years, the aerospace industry has grown from a new industry to a billion-dollar national effort. With the new applications and means of utilizing greater quantities of chemical energy in rocket vehicles, the methods for guaranteeing the safety of technical personnel as well as the general public have developed at an equivalent rate to the technology in propulsion. Safety features must be designed into the vehicles and facilities as a major factor in the development and use of rocket missiles.

This paper presents a brief review of the basic considerations in handling chemical rocket systems with respect to the current and near future large rocket propulsion vehicles used in the exploration of space. Safety aspects of the manufacturing process of high-energy propellants, transportation and handling of the finished material, and the development process from a new formulation to the test use are discussed, relating plant and public safety to the different phases of the operation.

Safety advantages of a new concept in rocket propulsion, the hybrid, are presented. This system offers the technical latitude to develop even larger, more powerful rocket vehicles and at the same time improve safety so that the fabrication and use of rockets is little more hazardous than running a large chemical plant or rubber tire factory.

2.0 FUNDAMENTALS OF CHEMICAL PROPULSION SYSTEMS

2.1 LIQUIDS

The chemical propulsion system, commonly referred to as a rocket motor, is a device for converting the thermochemical energy of one or more propellants into exhaust kinetic energy. The term "propellant" is applied to any material consumed in the rocket motor and may be either liquid or solid. Rocket motors differ from air-breathing propulsion systems in that they do not require air for combustion. Instead, propellants are used which are either oxidizer containing or decompose under temperature to liberate thermal energy.

The liquid rocket motor is so named because it employs propellants which are in the liquid phase, either under cryogenic or room temperature conditions. For example, the early German V-2 rocket used liquid oxygen and alcohol. More current typical liquid propellants include liquid oxygen as the oxidizer and kerosene or liquid hydrogen as the fuel.

Despite its apparent simplicity, the development of a reliable liquid propellant rocket engine having good performance chracteristics requires the solution of many complex problems which tend to increase with the size of the rocket.

The complete rocket must be light in weight but be capable of sustained operation at temperatures above 5000° F. Because of the large energy releases at high temperature and pressure, problems of ignition, combustion, and cooling are encountered. The selection of the propellants is governed to a significant extent by the application and logistics. Important factors include the maximum energy available per unit weight, safety in handling, dependability, storage qualities, and corrosive tendencies.

When dealing with highly reactive liquids in the very large quantities used in today's rocket boosters, the safety problems become of major concern.

Figure 1 is presented to illustrate the major components of a typical single motor booster stage employing both liquid oxidizer and fuel.

2.2 SOLIDS

Solid-propellant rocket motors offer advantages over liquids in many applications. These arise from greater simplicity, field handling ease and safety, good storage properties, and lower cost.

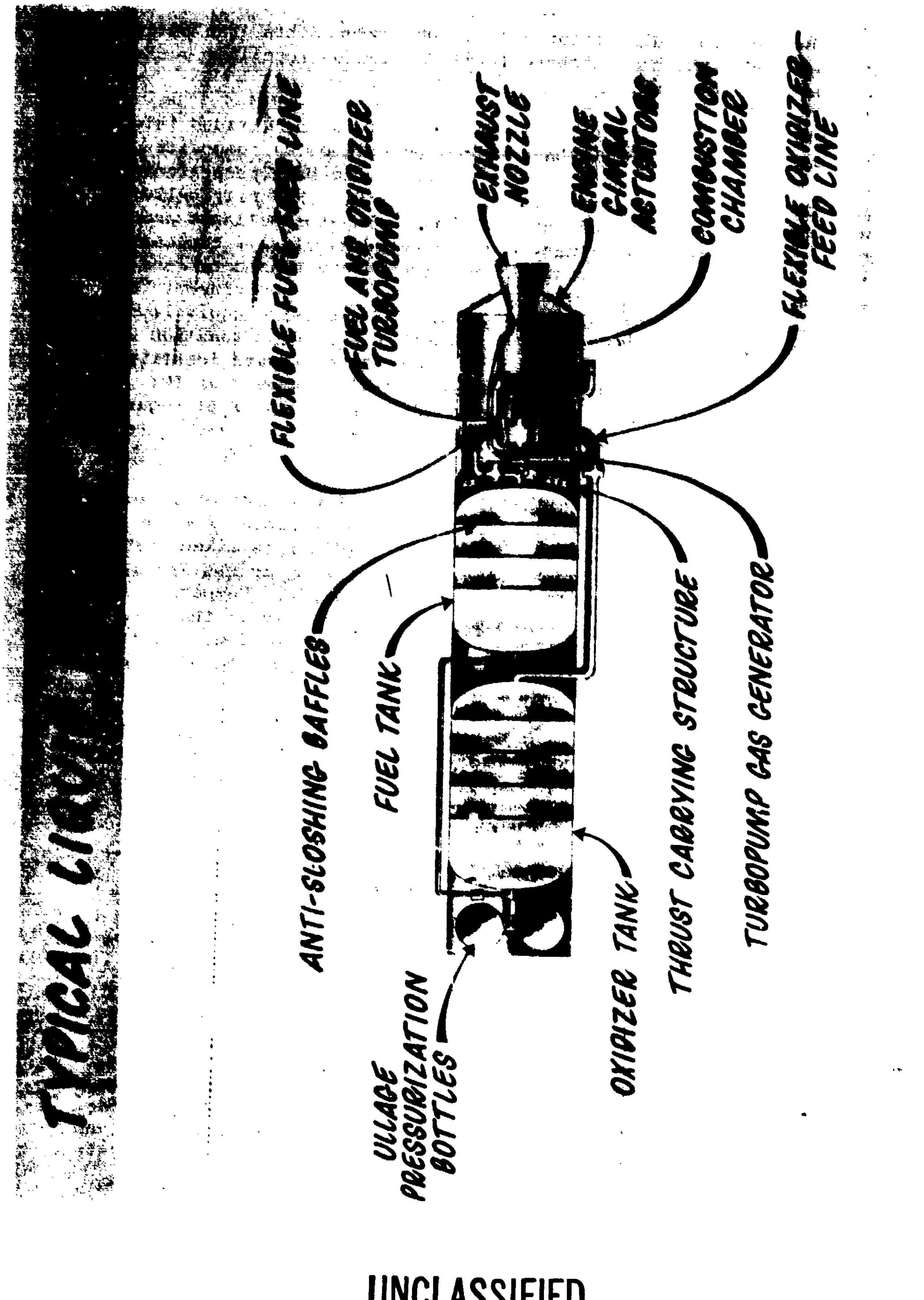

FIGURE 1

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Because the solid motor employs no moving parts, the potential failure modes which are inherent with a liquid-propellant rocket engine are minimized.

Figure 2. Solid-propellant rocket motors are divided into two basic classes: (1) double-base propellants, and (2) composite or heterogeneous propellants. In general, double-base propellants are gelatinized colloidal mixtures of nitroglycerin and nitrocellulose with stabilizing compounds added. Double-base propellants produce higher energy per unit weight but are rated as class 9 explosives; i.e., they will support detonation. The safety considerations associated with the use of class 9 propellants are stringent for manufacture, shipment, and usage. The TNT explosive equivalence for a class 9 propellant is 100 per cent; that is, the detonation of a quantity of such propellant would produce a shock wave identical to that produced by the explosion of an equivalent amount of TNT. For very large boosters, the amount of double-base propellant required would dictate extremely large distances between the launch site and other occupied areas.

Composite solid propellants are physical mixtures of a solid oxidizer and a fuel. The fuel also serves as a binder for the oxidizer particles. For these rocket motors, the oxidizer is mixed with the fuel and cast into the rocket case. Polymerizing agents are added to the mixture, which is then cured to a solid state. Composite solid propellants are generally rated as class 2 explosives; that is, they will not support detonation but will support combustion. Class 2 propellants offer a practical system for large space boosters because minimum safety requirements are needed.

In contrast, the current large liquid boosters employing liquid oxygen and kerosene have an explosive equivalence of approximately 20 per cent. Liquid oxygen and liquid hydrogen are rated as an explosive equivalence of 80 per cent. Figure 2 is presented to identify the major components of a typical solid-propellant space booster.

2.3 HYBRIDS

The hybrid rocket engine employs both liquid and solid elements. Normally, the oxidizer is the liquid and the fuel is solid.

Figure 3 is shown to illustrate the basic differences between the hybrid and the liquid and solid propulsion systems.

The hybrid propulsion system combines the principal advantages of both liquid and solid motors. Only one liquid flow system is required, which significantly reduces the number of components and possible failure modes. The major advantage of the hybrid is safety.

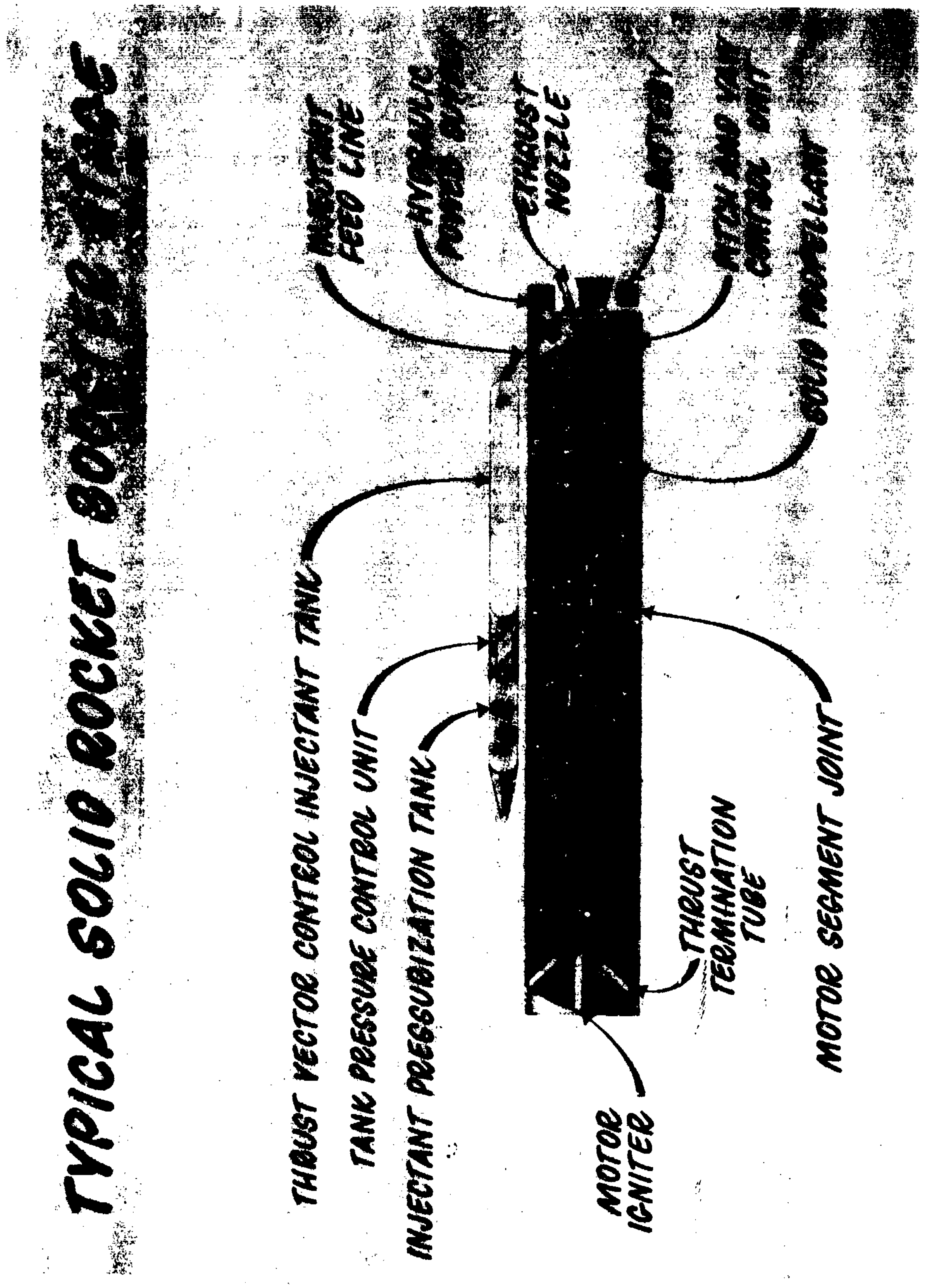
TYPICAL SOLID ROCKET
THRUST VECTOR CONTROL INJECTANT TANK
TANK PRESSURE CONTROL UNIT
INJECTANT PRESSURIZATION TANK
MOTOR IGNITER
THRUST TERMINATION TUBE
MOTOR SEGMENT JOINT
SOLID PROPELLANT
PITCH AND YAW CONTROL UNIT
EXHAUST NOZZLE
INJECTANT FEED LINE

FIGURE 2

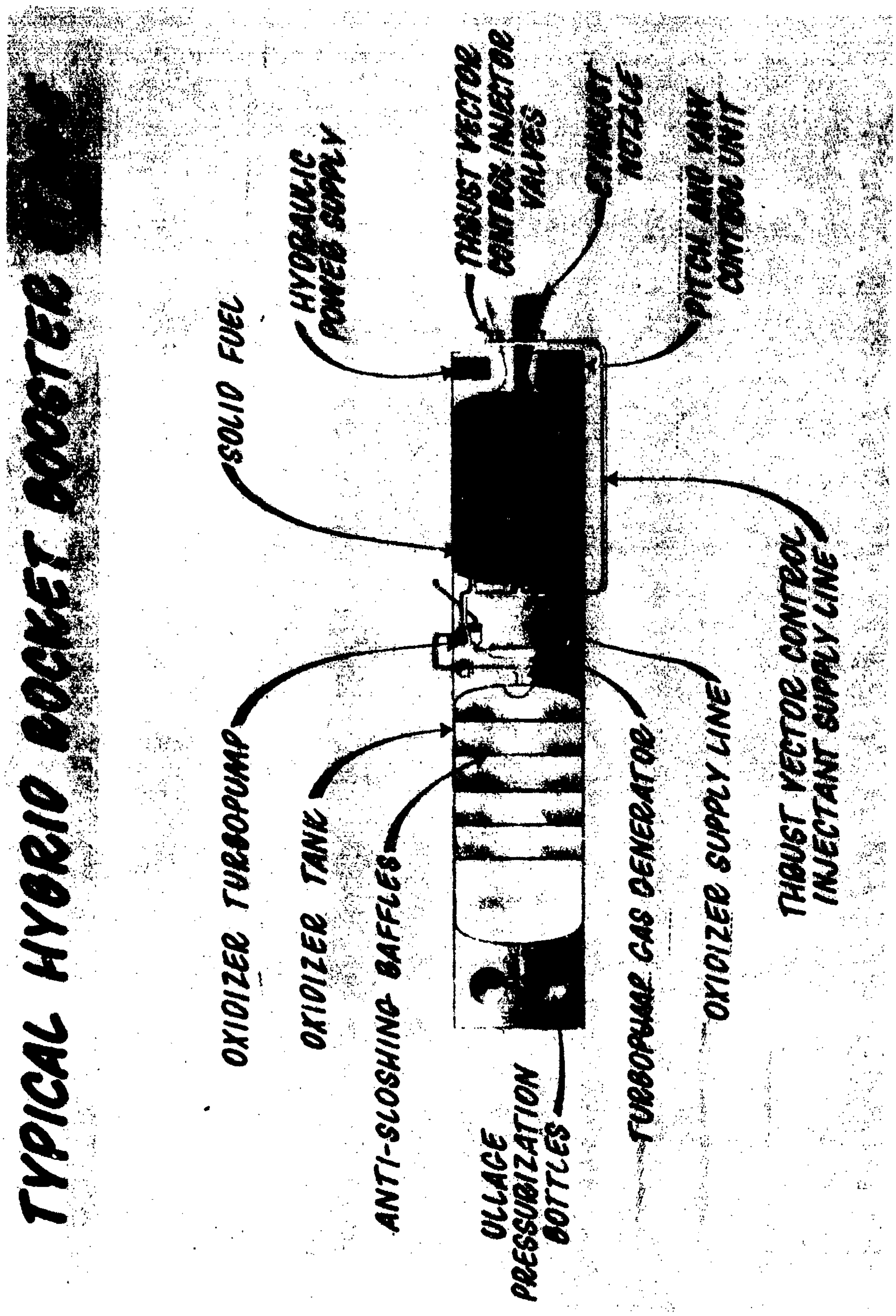
TYPICAL HYBRID ROCKET BOOSTER
SOLID FUEL
HYDRAULIC POWER SUPPLY
THRUST VECTOR CONTROL INJECTOR VALVES
EXHAUST NOZZLE
PITCH AND YAW CONTROL UNIT
THRUST VECTOR CONTROL INJECTANT SUPPLY LINE
OXIDIZER SUPPLY LINE
TURBOPUMP GAS GENERATOR
ULLAGE PRESSURIZATION BOTTLES
ANTI-SLOSHING BAFFLES
OXIDIZER TANK
OXIDIZER TURBOPUMP

FIGURE 3

Because both the liquid and solid fuels are inert, it is impossible either to achieve detonation or to sustain uncontrolled combustion. The key to this feature lies in the unique combustion process that governs the operation of the hybrid. Combustion occurs at a zone slightly away from the fuel surface, and is maintained by the vaporization of both the fuel and oxidizer.

Termination of oxidizer flow stops combustion instantly. Accidental ignition is not possible because a sequence of operations is employed to raise the surface temperature of the fuel to the point of vaporization (about 100° F). In general, a hypergolic liquid is introduced to react with the fuel and cause ignition. The oxidizer flow is then used to maintain combustion. Typical hybrid fuels include polybutadiene (rubber) and polymerized asphalt. The safety characteristics of these materials are optimum. Oxidizers used in hybrids range from nitric acid to liquid oxygen, and the conventional safety procedures used in handling these liquids are adequate. In hybrid propellant systems, the explosive equivalence is zero.

Thus, the hybrid space booster offers a practical means of lifting the large payloads currently being considered and at safety levels previously unattainable.

3.0 BOOSTER ROCKET SYSTEMS

3.1 CURRENT VEHICLES

Much of the early technology developed with liquid propellant IRBM's and ICBM's has been carried over into a class of standard launch vehicles in both intermediate and heavy payload ranges. These vehicles form the nucleus of the growing family of space boosters.

Figure 4 shows several of the vehicles commonly used for small to intermediate payloads. The Thor-Agena is an outgrowth of the early Thor ballistic missile. The Agena second stage developed specifically for space missions incorporates more advanced liquid technology and uses unsymmetrical dimethylhydrazine and inhibited red-fuming nitric acid as the propellant. The vehicle weighs 123,000 lb at lift-off, of which about 90 per cent is propellant.

The Scout (SLV-1A) is an all-solid vehicle which was specifically developed for space missions. As such, its cost effectiveness is significantly better than the converted ex-military ballistic missiles. The vehicle is much smaller than either the Thor or Atlas and is capable of orbiting approximately 300 lb.

The Atlas-Agena D is the largest of the converted liquid vehicles, weighing 275,000 lb at lift-off. Using liquid oxygen and kerosene as

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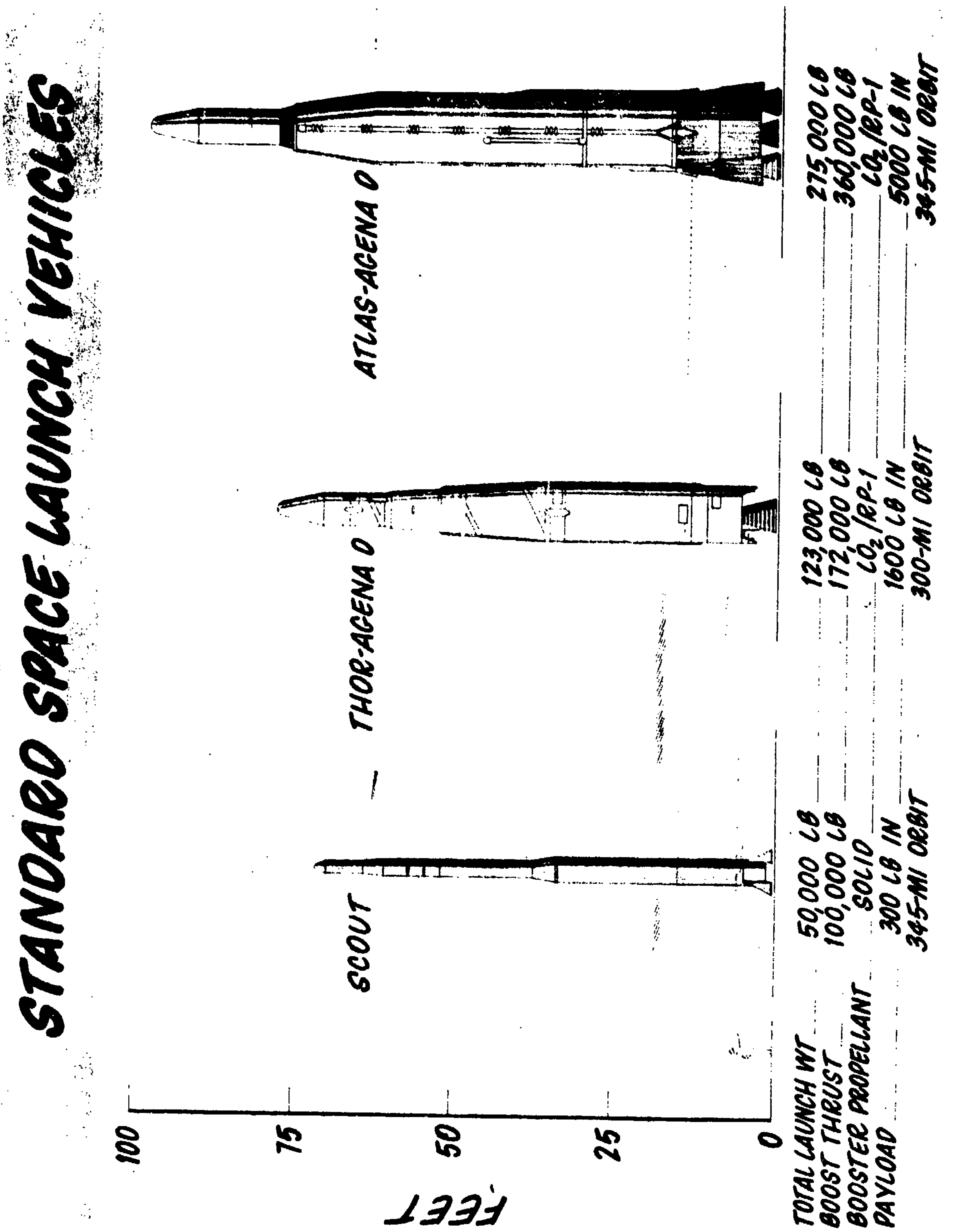

FIGURE 4

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the propellant, the TNT explosive equivalence is approximately 17,500 lb. The safety precautions necessary in handling a vehicle of this size are more stringent than for the smaller sizes.

With the advent of Apollo and the Air Force's Manned Orbiting Laboratory, it became necessary to develop a class of vehicles in the heavy payload range. Figure 5.

The Titan III-C, an outgrowth of the Titan ballistic missile, embodies a unique advanced concept. The core or central missile is a modified Titan II vehicle. The booster consists of a pair of strapped-on large solid rockets, each producing over 1,000,000 lb of thrust at lift-off and containing over 400,000 lb of solid propellant. The solid motors weigh approximately 500,000 lb each and are 120 in. in diameter. The TNT explosive equivalence is 10 per cent, or 80,000 lb of TNT.

The Saturn I-B represents the largest liquid vehicle currently operational with a lift-off weight of approximately 1,290,000 lb and a slightly greater payload capability than the Titan III-C. The first stage contains 890,000 lb of propellant (liquid oxygen and kerosene) with an explosive equivalence of 139,000 lb of TNT. The liquid vehicle with a comparable payload capability has over 50 per cent more explosive equivalence.

The Saturn V represents the largest liquid vehicle under development. With a liftoff weight of approximately 6,300,000 lb, over 4,550,000 lb are propellant (liquid oxygen and kerosene). The explosive equivalence of the booster is over 500,000 lb of TNT, or the equivalent to a one-half megaton nuclear warhead.

As the booster vehicle increases in size, so do the safety problems.

In order to protect operating personnel fully, vast distances are necessary to isolate the blast damage should an accidental explosion occur.

Should a low-altitude abort condition occur, the problem of disposing of the large quantities of propellant must be solved. Impacting a near fully loaded vehicle near the launch area would produce an explosion which would cause tremendous damage and potential loss of life.

3.2 PROJECTED GROWTH

Even larger vehicles are under consideration today. The Nova has been conceived as the space vehicle for manned planetary exploration. The booster could use the 260-in. diameter solid boosters currently being developed. Four such motors would make up the first stage and would have the explosive equivalence of 1,600,000 lb of TNT. It is

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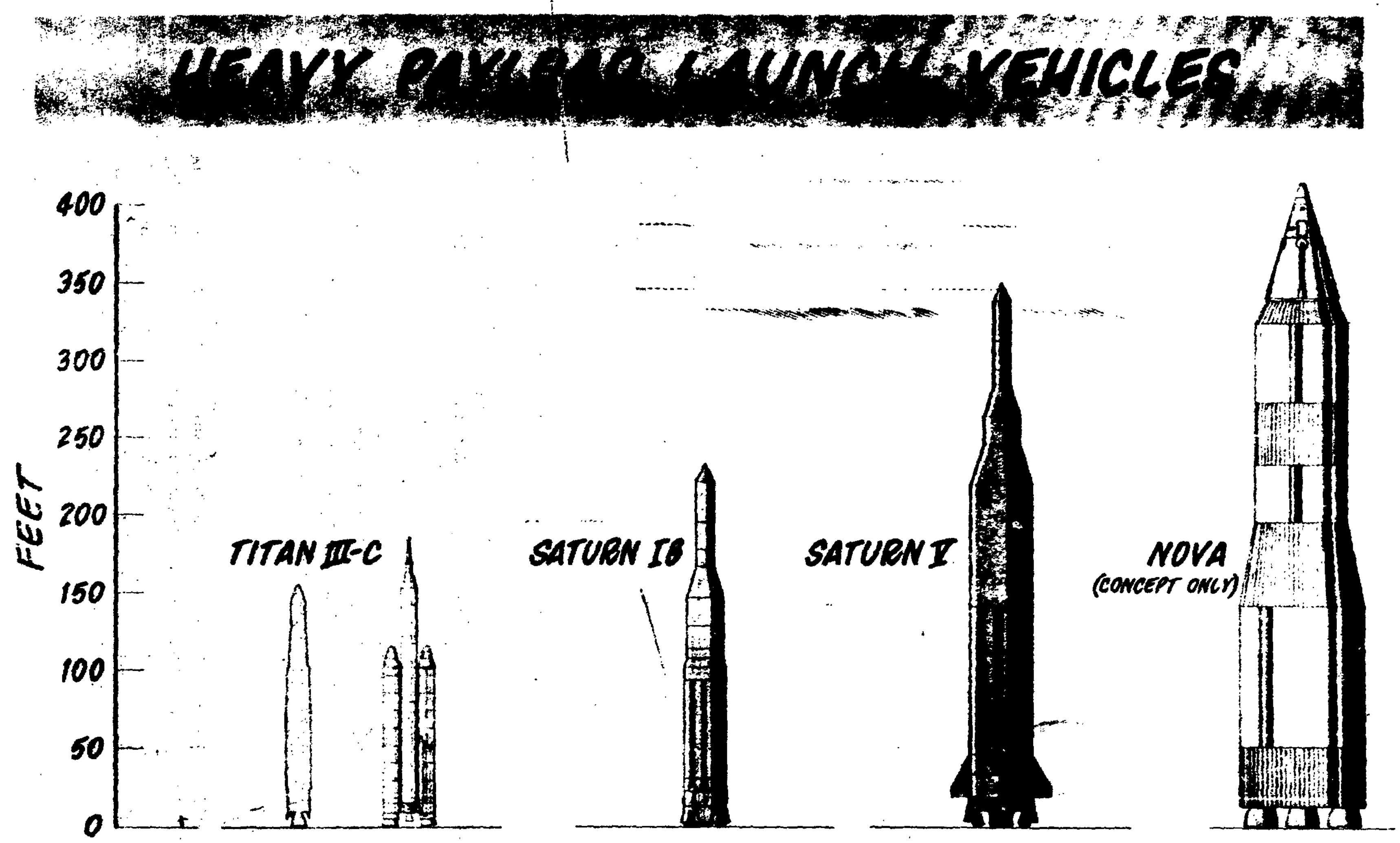

	TITAN III-C	SATURN IB	SATURN V	NOVA (CONCEPT ONLY)
TOTAL LAUNCH WT	1,230,000 LB	1,290,000 LB	6,800,000 LB	20,000,000 LB
BOOST THRUST	2,300,000 LB	1,500,000 LB	7,500,000 LB	30,000,000 LB
BOOSTER PROPELLANT	SOLID-CLASS 2	LO_2 / RP-1	LO_2 / RP-1	SOLID
PAYLOAD	25,000 LB IN 300-MI ORBIT	32,000 LB IN 300-MI ORBIT	220,000 LB IN 300-MI ORBIT	1,000,000 LB IN 300-MI ORBIT

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FIGURE 5

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doubtful whether enough vacant land exists in the Cape Kennedy area to provide the isolated launch site needed. If the boost stage were to employ liquid oxygen and hydrogen as propellant, the explosive equivalence would be 60 per cent, or approximately equivalent to 12,000,000 lb of TNT.

The safety advantages of using a class 2 solid propellant are clearly obvious. However, hybrid rocket technology offers promise of even greater safety advances. With an explosive equivalence of zero, such giant vehicles appear most practical and can use existing facilities and land.

3.3 MANUFACTURING ROCKET PROPELLANTS

The manufacturing problems associated with the large quantities of high-energy materials for large boosters present unique safety problems. The first major consideration is that of explosives. If at any time during manufacture or loading, liquid fuel and oxidizer are mixed, high hazard conditions prevail. To an even greater degree, the solid double-base propellants are extremely hazardous from the first handling of nitroglycerin to the final solid rocket motor grain. In addition, the ever-present high fire hazard and the incompatibility of most oxidizers with man present further safety problems in making propellants.

Remote operations are utilized significantly in the production of all current liquid and solid propellants. Processing is allowed to progress to a point that has a safety plateau or stabilized phase before operating personnel are allowed to be in close proximity. The common tools used to determine the safety conditions are closed circuit television and instrumentation which indicates temperature, pressure, time, and reaction status. All are limited to the degree of information they can provide about the process condition.

A final consideration of the production phase is the storage of ready material. When quantities of high-energy products are measured in the millions of pounds, even storage must have the isolation and control conditions of a rocket launch site to ensure safety.

In contrast to the conventional safety requirements for liquid and solid systems, the hybrid concept reduces the hazardous operations to that of handling liquid oxidizer. Because the fuel cannot be mixed easily with the oxidizer, detonation conditions are eliminated and fire conditions are reduced to surface contact. Fire hazards are reduced in order of magnitude over the competing systems.

3.4 TRANSPORTATION

A major problem after the completion of a rocket design and the manufacture of the propellants is to move the components from the fabrication site to the launch area. Assuming that the prevailing

conditions are the same as storage for the liquids and solids, the general safety concern to the public during transportation would be that of fire or explosion.

The hybrid concept reduces the transportation problem to one of moving inert parts. Because the oxidizer can be supplied at the launch site or shipped by tank car, it presents the same safety problem for a hybrid as for liquid systems. The fuel, which is inert, can be shipped or handled like rubber. In cases where the logistics of transportation are a problem, it is possible to either ship building blocks of fuel or actually set up an on-site batch plant and fabricate the fuel where it is to be used. All this is possible because processing of the hybrid fuel is similar to making cheap rubber and no remote controls are required. The hybrid concept also allows complete inert operating conditions during rocket build-up and flight ready conditions because the oxidizer can be loaded at the last minute after all tasks requiring manned supervision have been checked. Thus a minimum hazard condition prevails throughout the assembly of a hybrid booster system. The public is not exposed to conditions that are even as hazardous as bulk gasoline transportation, and the safety of technical personnel using the components is reduced to that during construction of any large structure.

4.0 SAFETY MEASURES EMPLOYED DURING THE TEST AND USE OF PROPELLANTS

Rocket propellant development begins with safety. In the laboratory all new formulation specimens are handled and tested as though they were toxic, sensitive explosives. Only after conclusive qualification tests have been conducted and the true characterization of the propellant established are the handling procedures reduced to a specific level for the formulation. In all early tests, the specimen size is kept at a maximum of 10 grams in any one quantity. As more is known about the formula, the quantity size is increased up to 10 lb for storage. Working samples are still used in gram sizes.

After initial studies, a development qualification program is conducted to determine the effects of process variables, aging, heat and cold, humidity, reaction with potential normal contaminants such as salt water, dust, and sand, and finally the effects of physical strain and vibration. In all tests, the qualification specifications are established on actual anticipated end usage and environmental conditions that could exist. The limits are statistically set to provide assurance of safe product compliance within the operating conditions to which the propellant is exposed.

The next step in the use of high-energy propellants is the application to a mission. The mission cannot exceed the safety limits of the propellant. The manufacture, transportation, and loading of the

propellant dictate specific safety measures. To these are added the safety requirements for a man-rated vehicle. The safety considerations center on malfunction or component failure that might result in a threat to the astronaut or the firing crew. The two main points of the man-rated rocket mission that require extra safety measures are:
(1) the hold fire or disassembly of a rocket vehicle, and (2) the mission abort or destruction of a vehicle after lift-off. These phases vary in degrees of handling problems according to the propellant. In liquid boosters, the fluids must be drained and the material cleaned or purged from the tankage if the unit is disassembled. Any spillage may cause problems because the fuel is combustible in air. Mixtures of fuel and oxidizer may explode.

Solid propellants always have a fire hazard condition; consequently, the handling operations must always be conducted accordingly.

The hybrid offers the greatest safety because the oxidizer can be vented or pumped away, and the system is inert again. Spillage presents only minor fire hazards unless some added item such as oil provides a fuel. This minimizes hazardous conditions even for the multi-million-pound vehicles.

5.0 SUMMARY

Safety has, by necessity, played a significant part in the continued growth and progress of the aerospace industry. The techniques and procedures for working with high-energy chemicals reflect the respect for safety that must accompany working with such quantities of energy.

The size of the systems, the necessary manufacture, fabrication, transportation, final assembly, and use demand safe practices. The new hybrid technology presents the key to further progress without compromising the safety of those who work with the rockets or the safety of those who could become the victims of accidental release of such quantities of energy.

Colitti, Picatinny Arsenal: You showed a theoretical specific impulse of 375 pound sec. per pound in a vacuum, could you tell me what you are delivering under atmospheric conditions?

Weilmuenster: Yes. It depends of course upon the system itself. This little unit I have here is plexiglass which is poly-methyl-methylacrylate and oxygen. The theoretical there is 290 and of course we're delivering within 90% of that particular theoretical value. In some of the other systems, fluorine containing systems, a complex oxidizer such as the gentleman before me described and there are sophisticated ways of making them.. Some of those fluorine containing oxidizers with a rubber type polymer. We of course are delivering 300 and over, theoretical being a little bit above 300. Some are around 325. So with the plenum chambers, you may have noticed fore and aft mixing chambers. Then we can and are realizing these combustion deficiencies and these impulses that I talked about. This little unit here does not have a sophisticated injector because after all, its a little unit to demonstrate and if you'd step up here later, you can see that regression is greater at the point of injection than it is downstream or because we have no plenum chamber mixing devices present. When we do have these mixers present we are experiencing these deficiencies.

Sgt. Law, ATC: Regarding the Titan IIIC thrust-vector control system. Is there an attempt here at hybrid burning in the thrust vector control when you introduce the nitrogen-tetroxide or is this strictly a shock front arrangement?

Weilmuenster: No, there's no hybrid technology involved at all, its just injecting N_2O_4 thru a secondary injection at the nozzle with a myriad of holes around the collar or the exit cone and this of course is programmed into the picture. You have guidance by three different jetivators or secondary injector or the gimbaling affair and of course the secondary injection was found and believed to be the one with the least possibility of mechanical failure and this sort of thing.

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MEMORANDUM FOR DDESB RECORDS

SUBJECT: Declassification of Explosives Safety Seminar Minutes

References: (a) Department of Defense 5200.1-R Information Security Program, 14 Jan 1997

(b) Executive Order 12958, 14 October 1995 Classified National Security Information

In accordance with reference (a) and (b) downgrading of information to a lower level of classification is appropriate when the information no longer requires protection at the originally level, therefore the following DoD Explosives Safety Seminar minutes are declassified:

a. AD#335188 Minutes from Seminar held 10-11 June 1959.
b. AD#332709 Minutes from Seminar held 12-14 July 1960.
c. AD#332711 Minutes from Seminar held 8-10 August 1961.
d. AD#332710 Minutes from Seminar held 7-9 August 1962.
e. AD#346196 Minutes from Seminar held 20-22 August 1963.
f. AD#456999 Minutes from Seminar held 18-20 August 1964.
g. AD#368108 Minutes from Seminar held 24-26 August 1965.
h. AD#801103 Minutes from Seminar held 9-11 August 1966.
i. AD#824044 Minutes from Seminar held 15-17 August 1967.
j. AD#846612 and AD#394775 Minutes from Seminar held 13-15 August 1968.
k. AD#862868 and AD#861893 Minutes from Seminar held 9-10 September 1969.

The DoD Explosives Safety Seminar minutes listed above are considered to be public release, distribution unlimited.

DANIEL T. TOMPKINS
Colonel, USAF
Chairman

Attachments:
1. Cover pages of minutes

cc:
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MINUTES
OF THE SEVENTH
EXPLOSIVES SAFETY SEMINAR
ON
HIGH-ENERGY PROPELLANTS

Carriage House Motor Lodge
Cocoa Beach, Florida

24-26 August 1965

Sponsor

ARMED SERVICES EXPLOSIVES SAFETY BOARD
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UNITED STATES AIR FORCE

271 attendees

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